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Modular Multipurpose Space Station Study

Section 3 - MODULAR SPACE STATION DESIGN (1)

Section 3.1–MODULAR CONFIGURATIONS

Section 3.2–RADIATION SHIELDING

Section 3.3–STRUCTURAL DESIGN

Section 3.4–WEIGHT ANALYSIS

FINAL REPORT

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A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

VOLUME INDEX

MODULAR MULTIPURPOSE SPACE STATION STUDY

The complete study, consisting of six sections, an appendix, and a condensed summary, is contained in the following seven volumes.

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TABLES

TABLES (Continued)

Section 3

MODULAR SPACE STATION DESIGN

The modular concept is concerned with the evolutionary growth of a family of space stations that will become available during, or immediately after, the Apollo Extension System (AES) and extending into the 1980's or beyond. Starting with Apollo subsystems and technology, the development of advanced subsystems and configurations can be spread over a broad time base, thereby maintaining research and development efforts at a low level. Further, this building block approach facilitates program control and flexibility of funding since new developments can be incorporated into the program at essentially any point.

The basic modular structural components are illustrated in Fig. 3-1. They consist of a cylindrical wall structure, floor interconnect assembly, flat floor assembly, and a bulkhead assembly. All of the space station configurations considered in this report can be constructed from these basic structural components. Standard or universal hatches are provided in each bulkhead assembly and at diametrically opposed points in the wall structure. The bulkhead hatches provide access between adjacent compartments, docking ports for spacecraft, and attachment points for external experimental equipment. The sidewall hatches are intended primarily for external experiment attachment, windows, and wall penetrations for experiments, but can also be used for docking ports. In the case of the Interim or Operational Modular Multipurpose Space Station, these sidewall hatches can be used for the attachment of intercompartment access tubes. The floor interconnect assembly, which can assume a variety of forms (to be discussed subsequently), reduces floor and ceiling deflections from internal pressure to an acceptable amount and helps assure open lanes of communication between compartments.

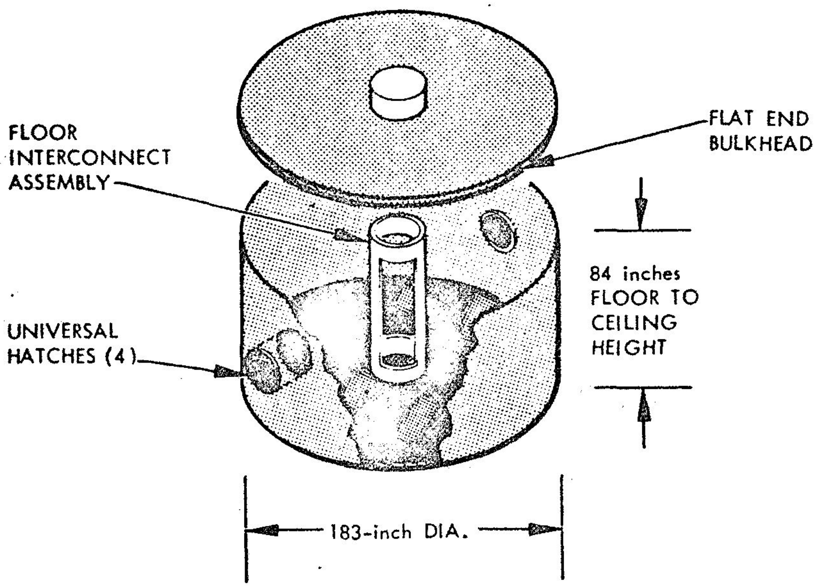


FIG. 3-1 BASIC MODULAR STRUCTURAL CONCEPT

Subsystems for the Modular Space Station configurations assume two forms of evolution depending on the subsystem. The Electric Power subsystem, for example, is completely modularized on the basis of additive fuel cell or solar array modules; the Environmental Control subsystem, on the other hand, evolves to a semi-closed ecology through the addition of components. Either type of subsystem, in its evolution, can accept advances in technology, as is shown in the following sections of this report.

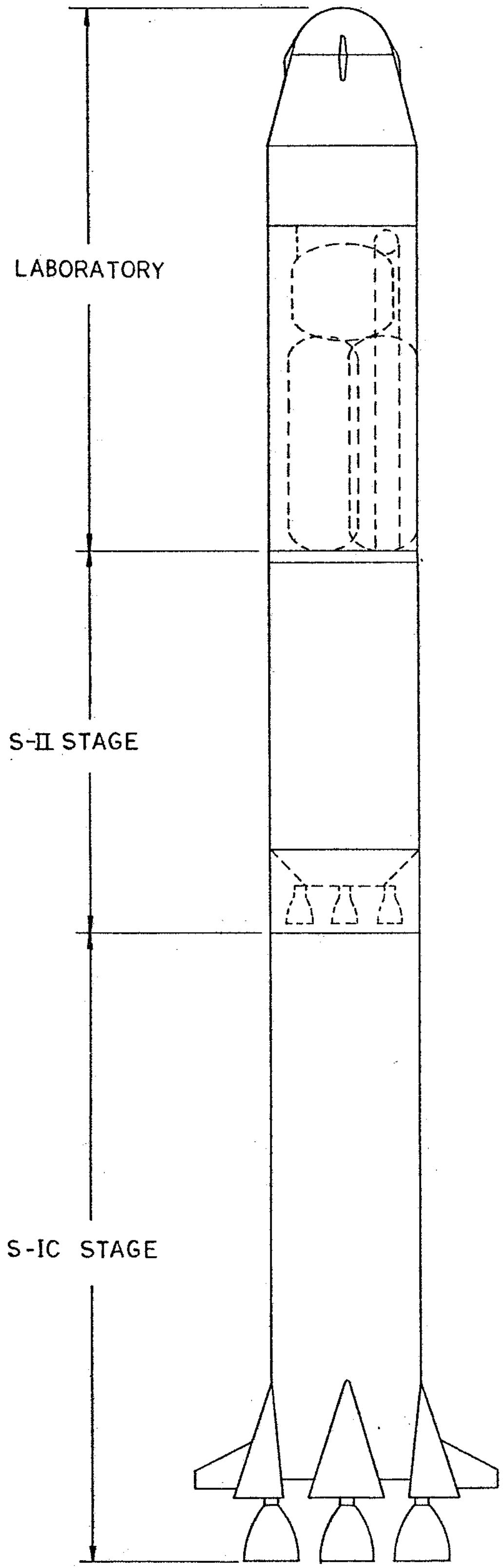
Each of the Modular Space Station configurations must be compatible with the contemplated versions of the Saturn launch vehicle family. For the space station orbits under consideration, the Saturn payload capabilities specified from Cape Kennedy are as follows:

- Saturn IB:
  200 n.mile, 28.5 deg inclination -- 36,800 lb

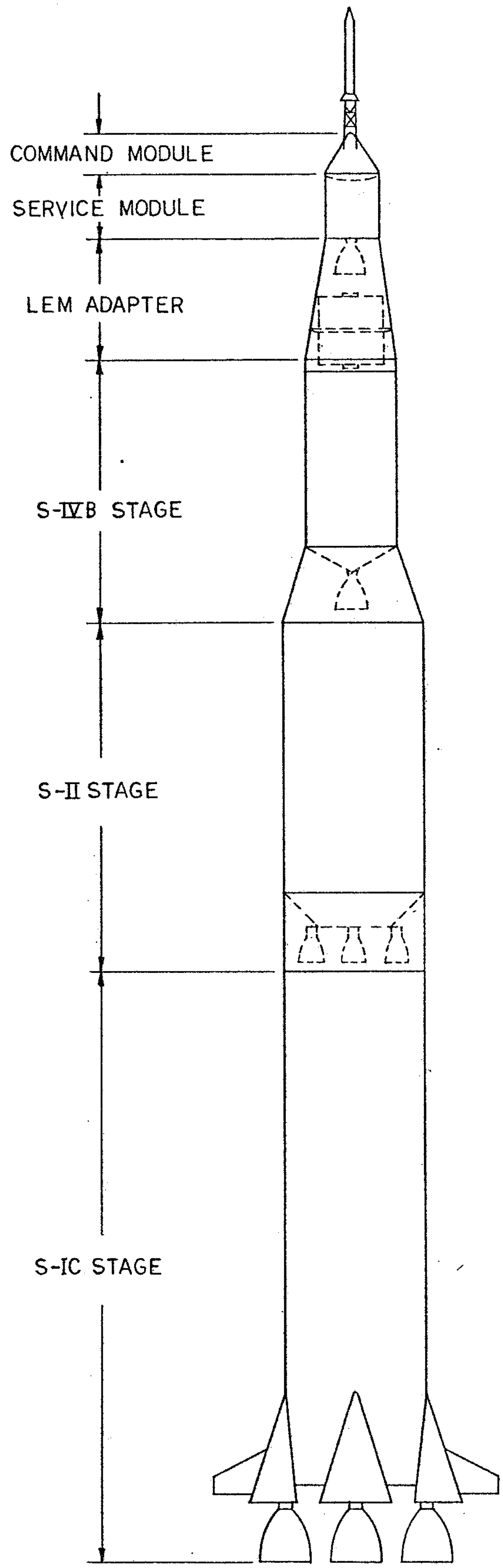
- Saturn V (3 stage):
  200 n.mile, polar orbit -- 41,000 lb
  30 deg, earth synchronous -- 63,000 lb
- Saturn V (2 stage):
  260 n.mile, 29.5 deg orbit -- 247,500 lb

The launch configurations for modular configurations are as shown in Fig. 3-2. The flight profiles, showing staging, orbital operations, and crew recovery for each of the six missions under consideration are shown in Figs. 3-3 through 3-8.

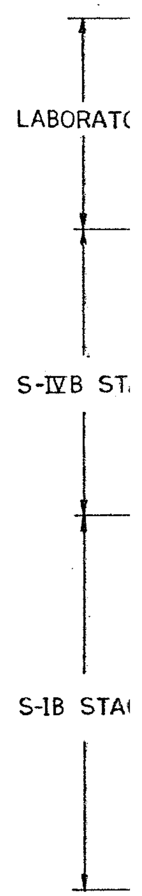
The following sections of this report define in conceptual detail the modular space station configurations, subsystems and capabilities that are compatible with the launch vehicles, state-of-the-art, schedules and fiscal funding that are available to the nation in the near future.

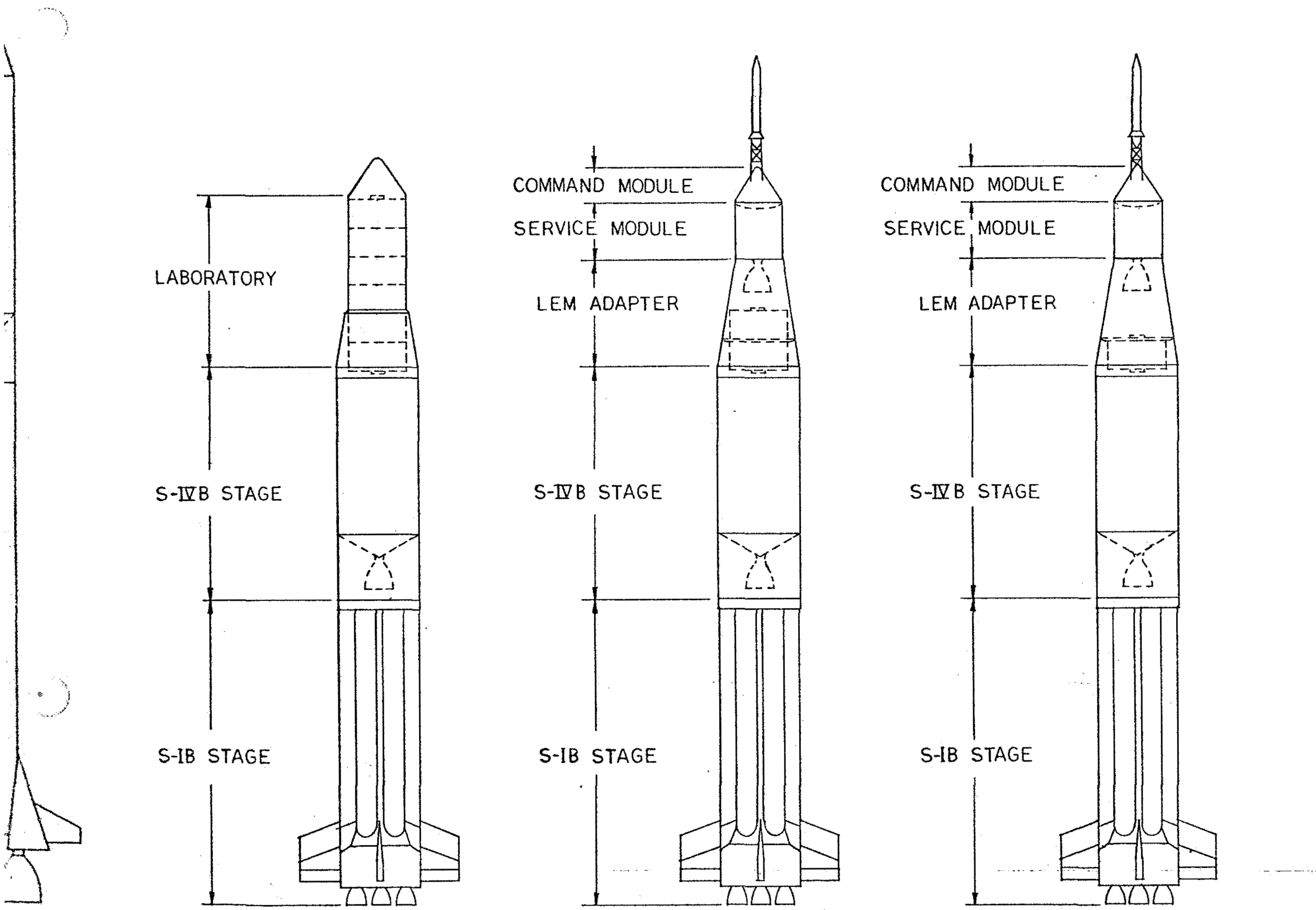


S-V LAUNCH CONFIGURATION
OPERATIONAL STATION
29.5°-260 N.M. ORBIT



S-V LAUNCH CONFIGURATION
TWO-COMPARTMENT LAB
POLAR OR SYNCHRONOUS ORBIT





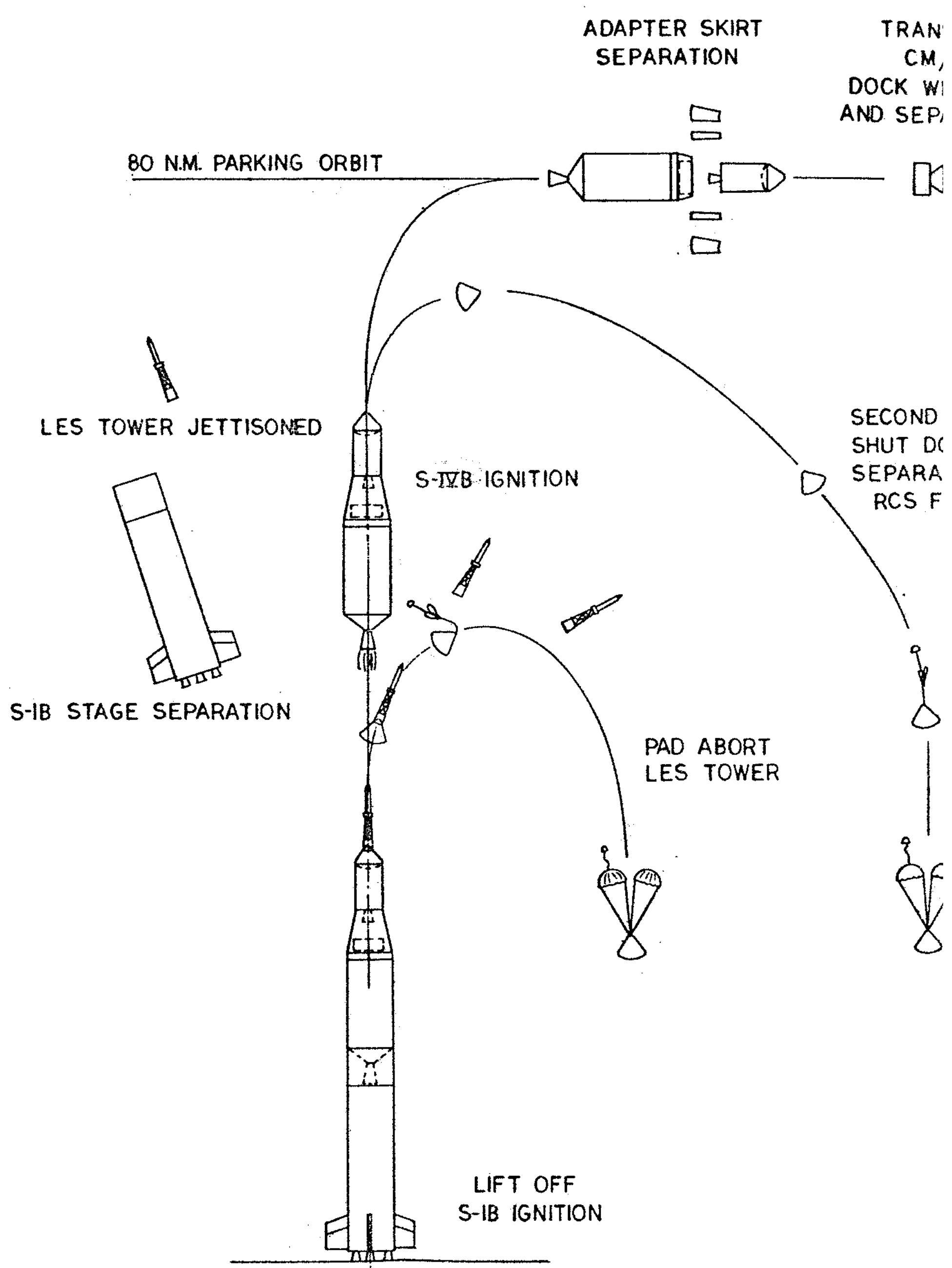
GURATION
NT LAB
VOUS ORBIT

S-IB LAUNCH CONFIGURATION
INTERIM STATION
28.5°-200 N.M. ORBIT

S-IB LAUNCH CONFIGURATION
TWO-COMPARTMENT LAB
28.5°-200 N.M. ORBIT

S-IB LAUNCH CONFIGURATION
ONE COMPARTMENT LAB
28.5°-200 N.M. ORBIT

FIG. 3-2 LAUNCH CONFIGURATIONS, MODULAR MULTIPURPOSE SPACE STATIONS


ADAPTER SKIRT SEPARATION
80 N.M. PARKING ORBIT
LES TOWER JETTISONED
S-IVB IGNITION
S-IB STAGE SEPARATION
PAD ABORT LES TOWER
LIFT OFF S-IB IGNITION

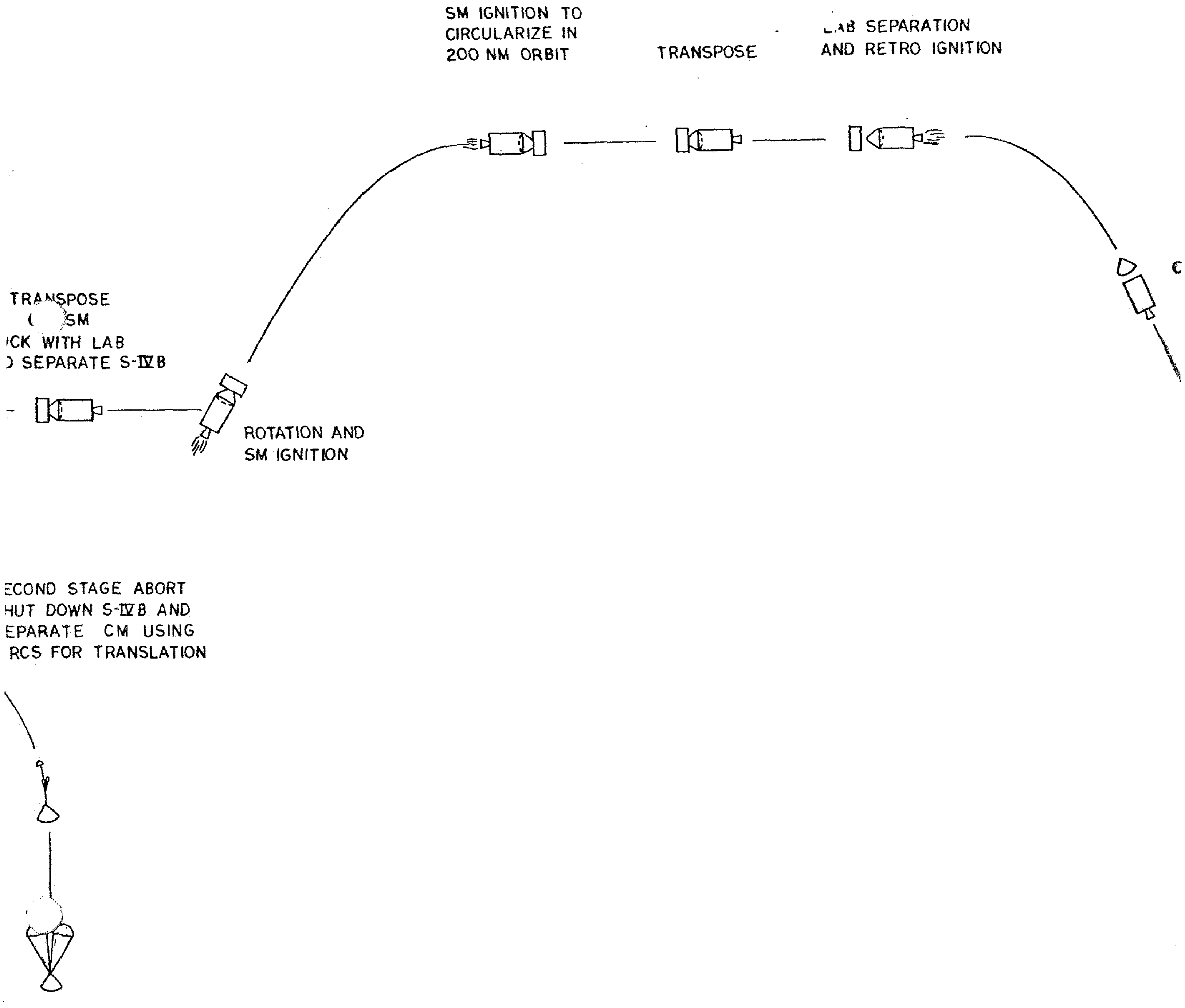


FIG. 3-3 MISSION PROFILE, ONE-COMPARTME

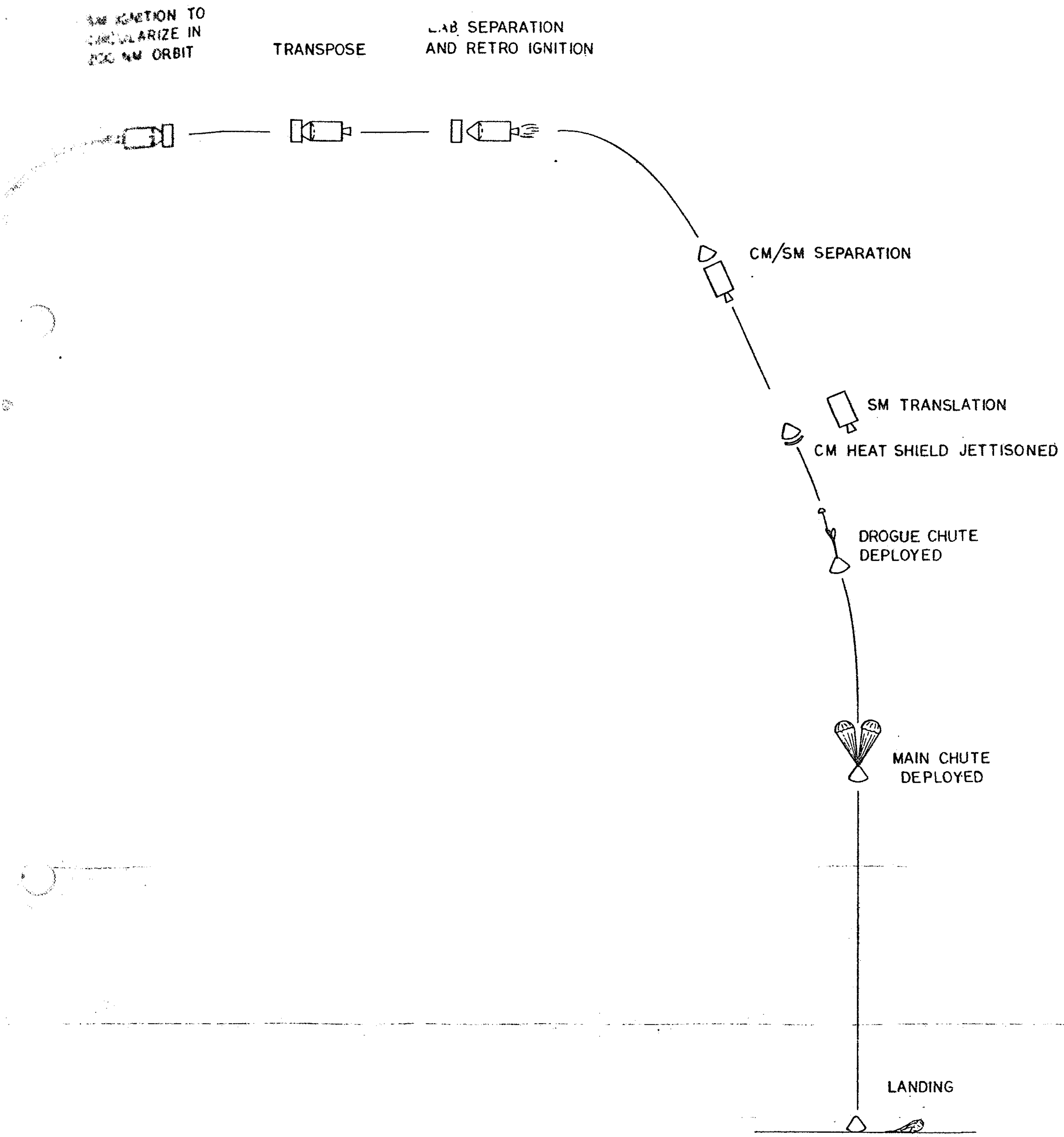
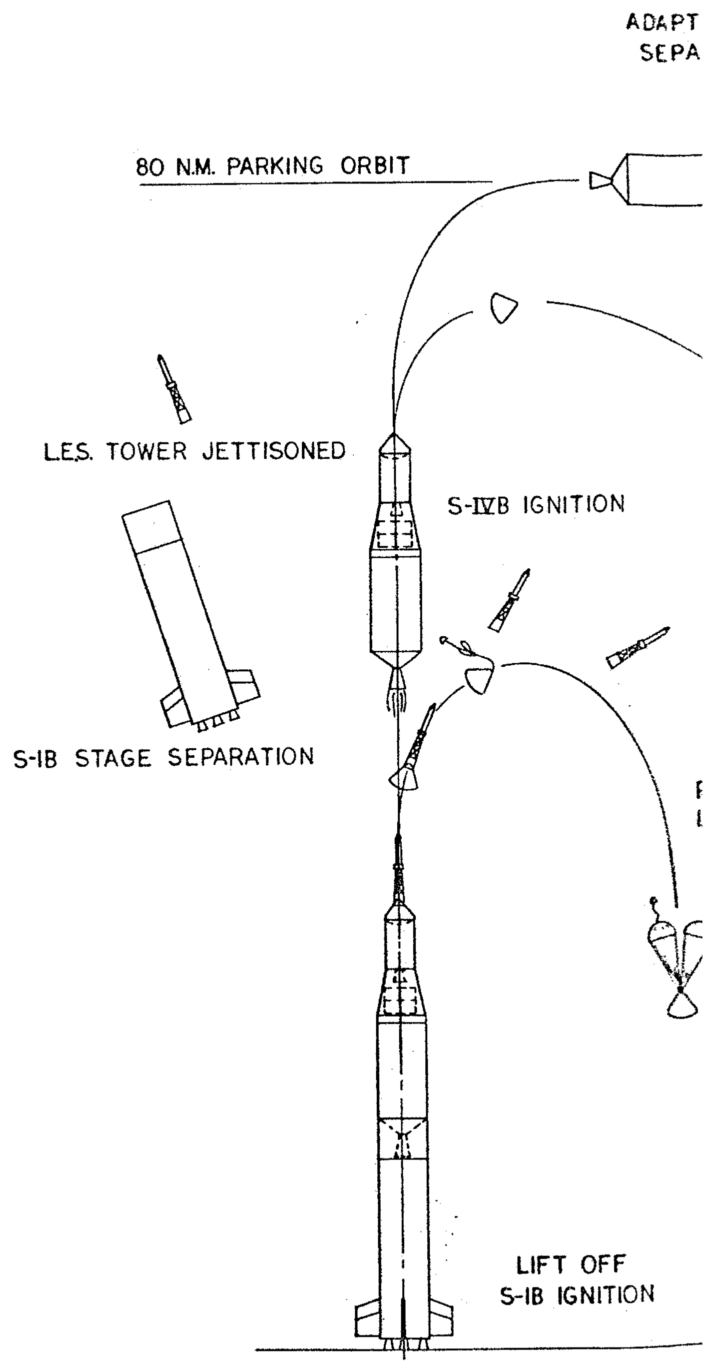
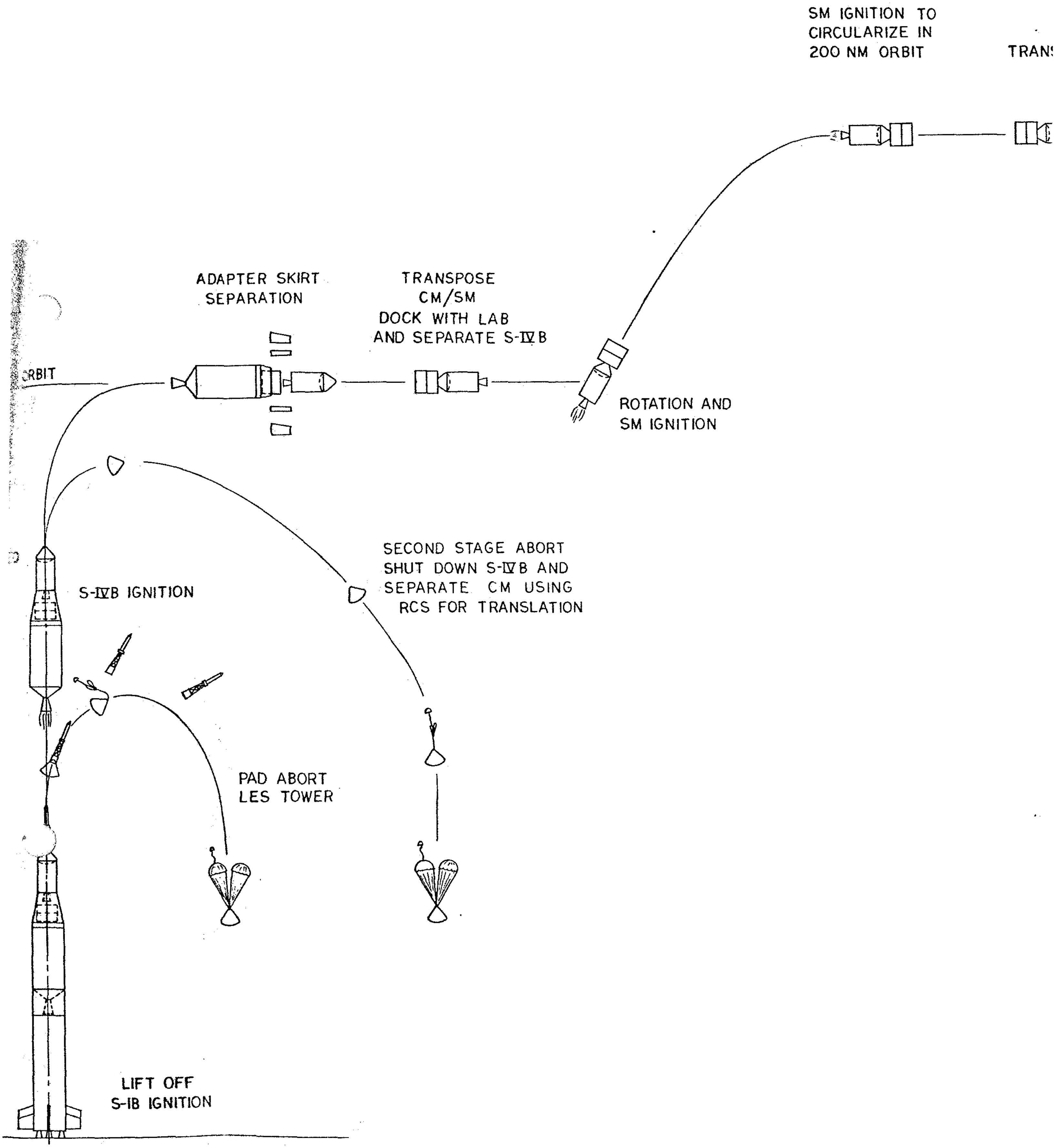


FIG. 3-3 MISSION PROFILE, ONE-COMPARTMENT LABORATORY



ADAPT
SEPA
80 N.M. PARKING ORBIT
L.E.S. TOWER JETTISONED
S-IVB IGNITION
S-IB STAGE SEPARATION
LIFT OFF
S-IB IGNITION



SM IGNITION TO
CIRCULARIZE IN
200 NM ORBIT
TRANS
ADAPTER SKIRT
SEPARATION
TRANSPOSE
CM/SM
DOCK WITH LAB
AND SEPARATE S-IVB
RBIT
ROTATION AND
SM IGNITION
SECOND STAGE ABORT
SHUT DOWN S-IVB AND
SEPARATE CM USING
RCS FOR TRANSLATION
S-IVB IGNITION
PAD ABORT
LES TOWER
LIFT OFF
S-IB IGNITION

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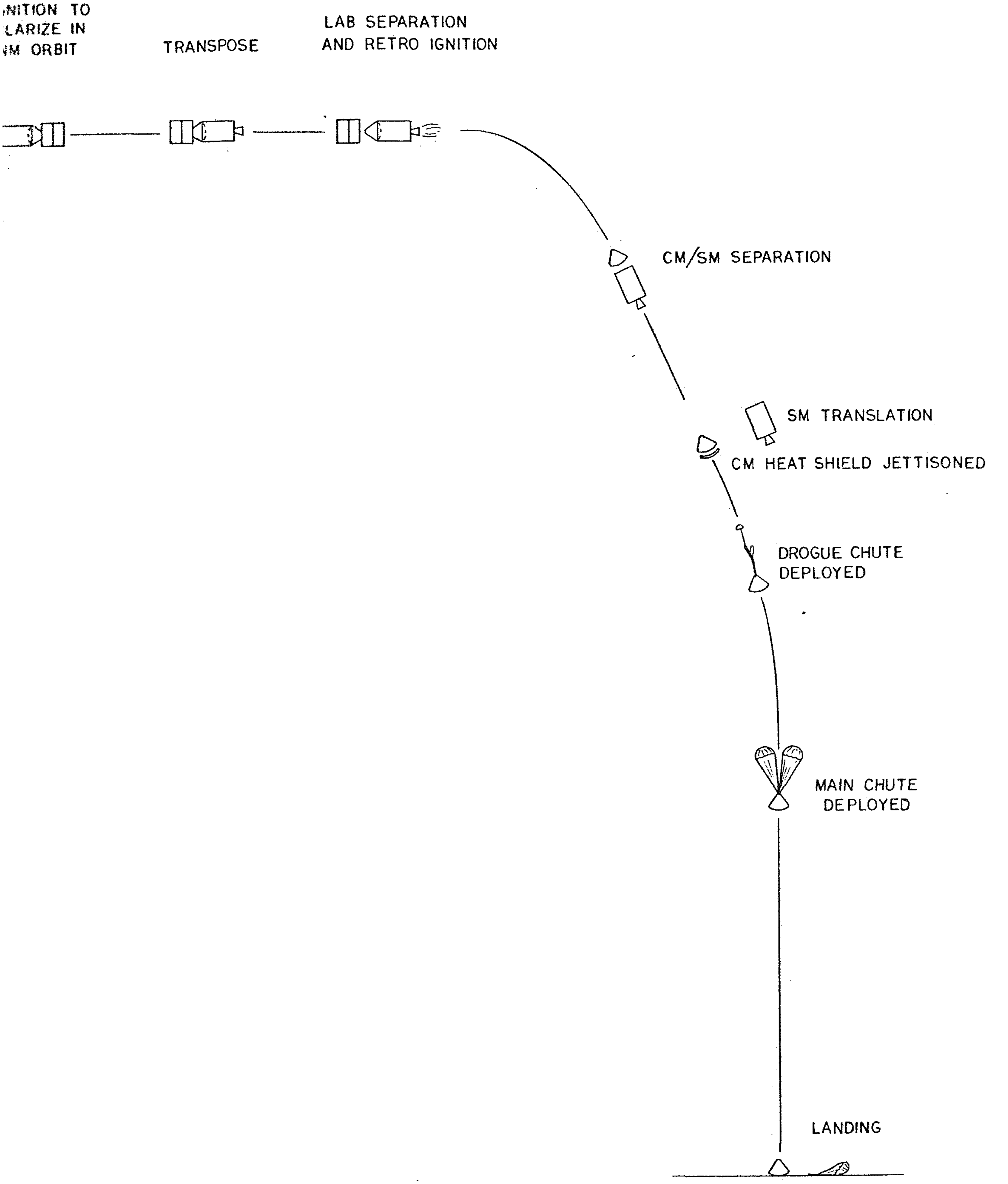
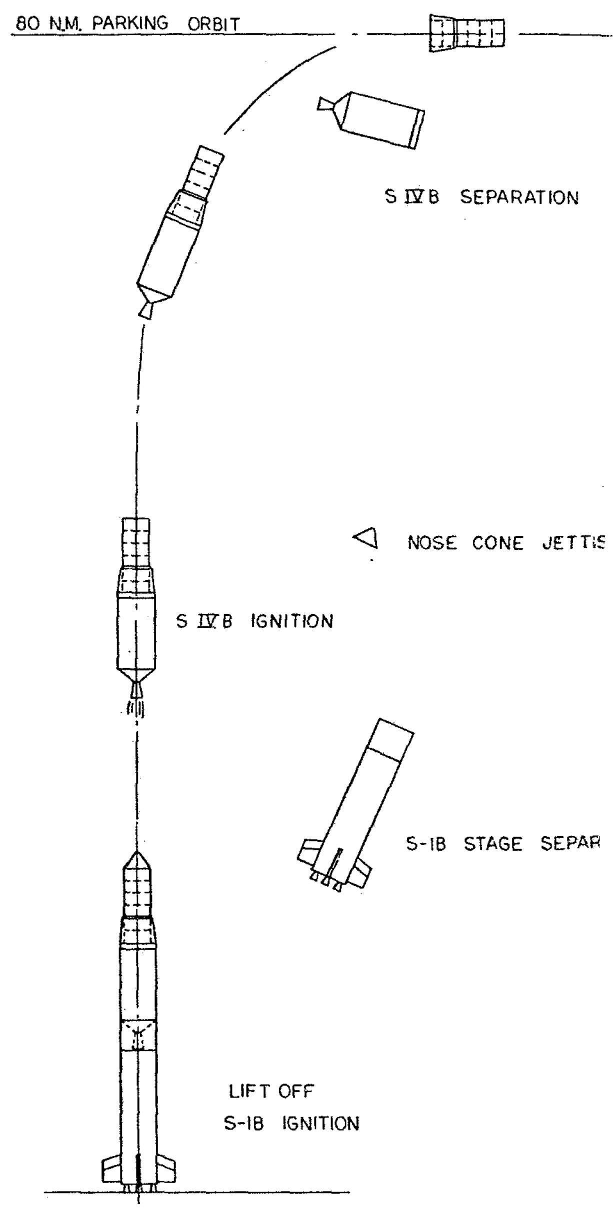
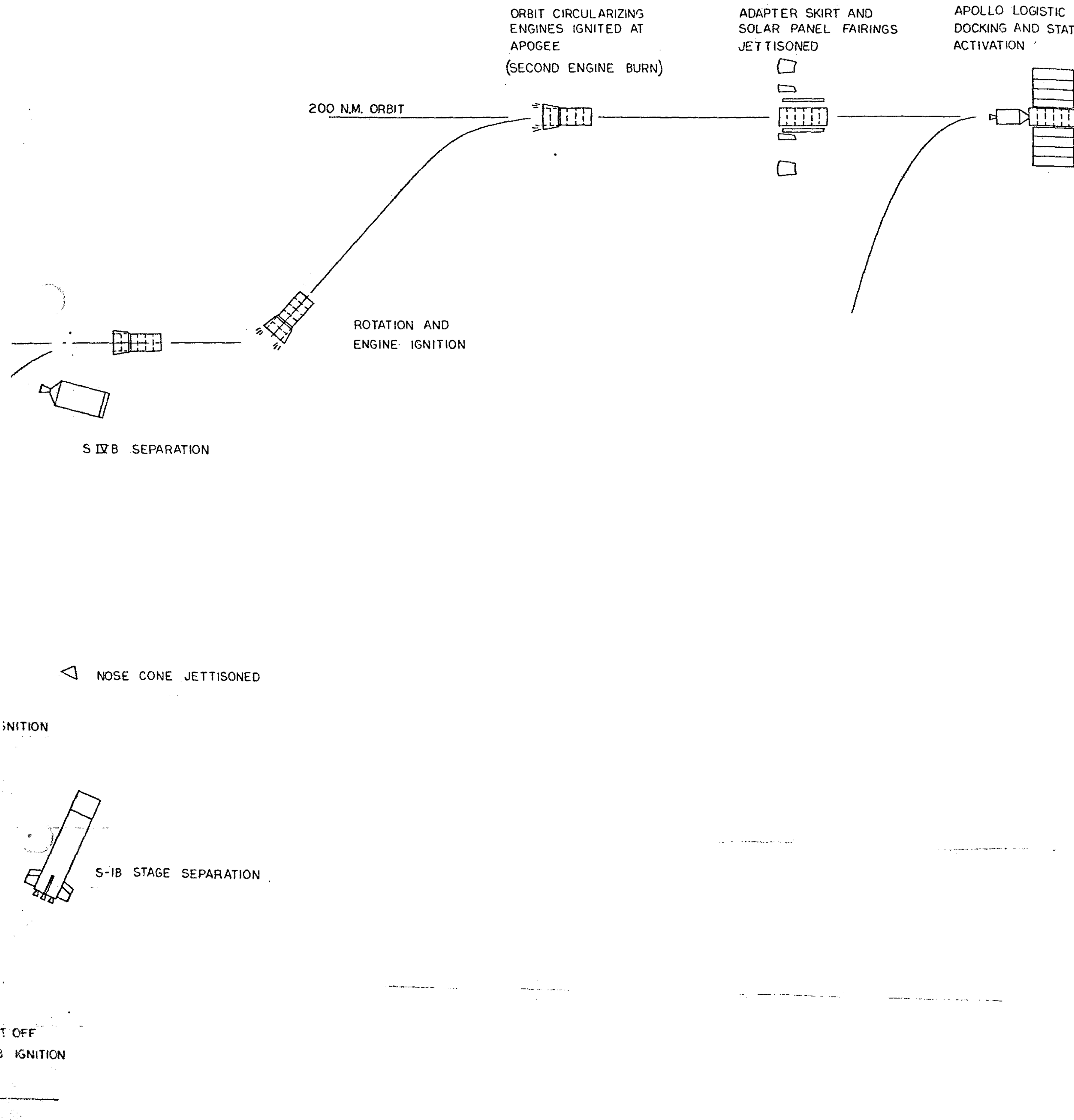


FIG. 3-4 MISSION PROFILE, TWO-COMPARTMENT INDEPENDENT LABORATORY



80 N.M. PARKING ORBIT
S IVB SEPARATION
NOSE CONE JETTIS
S IVB IGNITION
S-IB STAGE SEPAR
LIFT OFF
S-IB IGNITION



ORBIT CIRCULARIZING ENGINES IGNITED AT APOGEE
(SECOND ENGINE BURN)
ADAPTER SKIRT AND SOLAR PANEL FAIRINGS JETTISONED
APOLLO LOGISTIC
DOCKING AND STAT
ACTIVATION
200 N.M. ORBIT
ROTATION AND ENGINE IGNITION
S IVB SEPARATION
NOSE CONE JETTISONED
NITION
S-IB STAGE SEPARATION
OFF
IGNITION

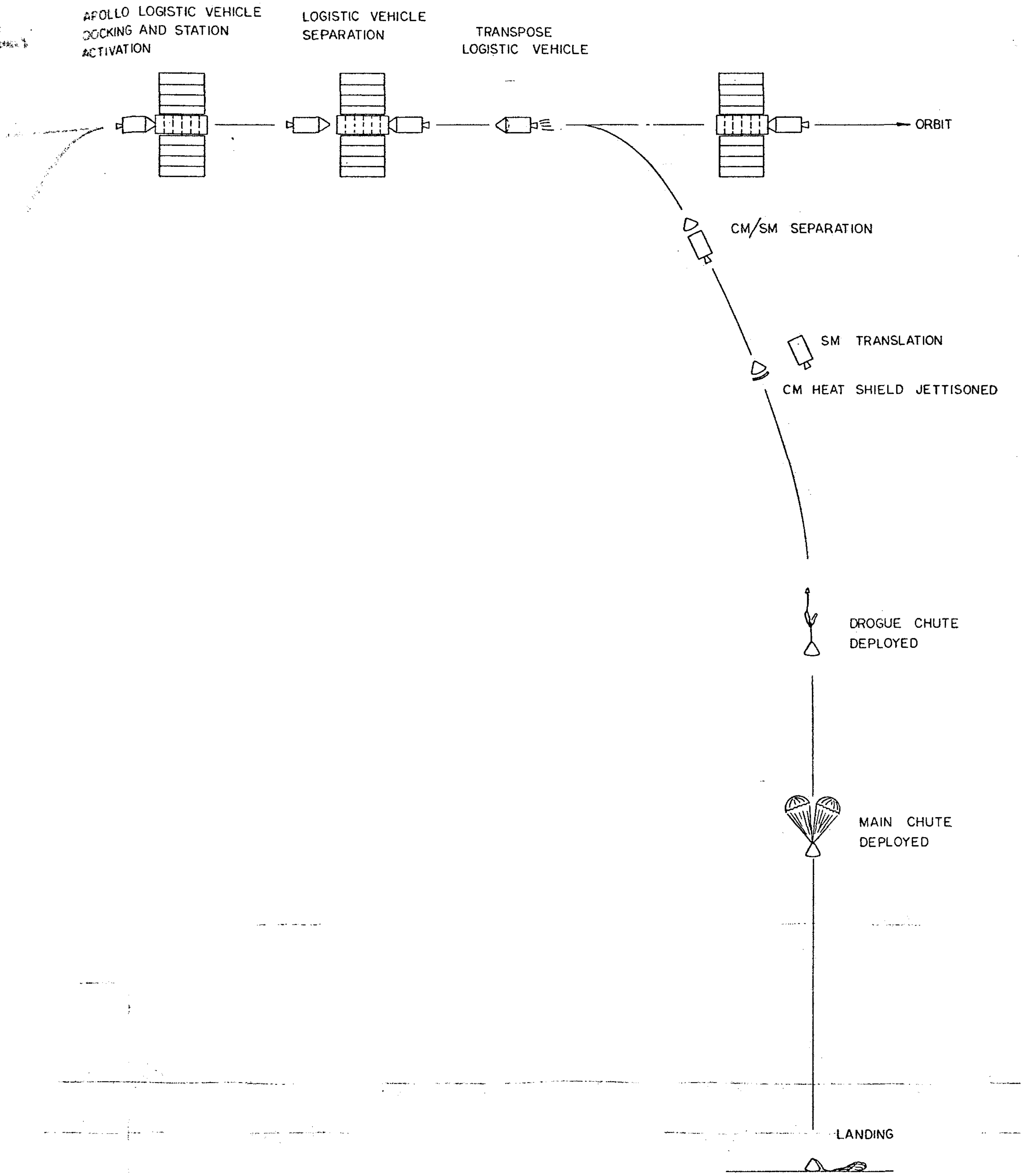
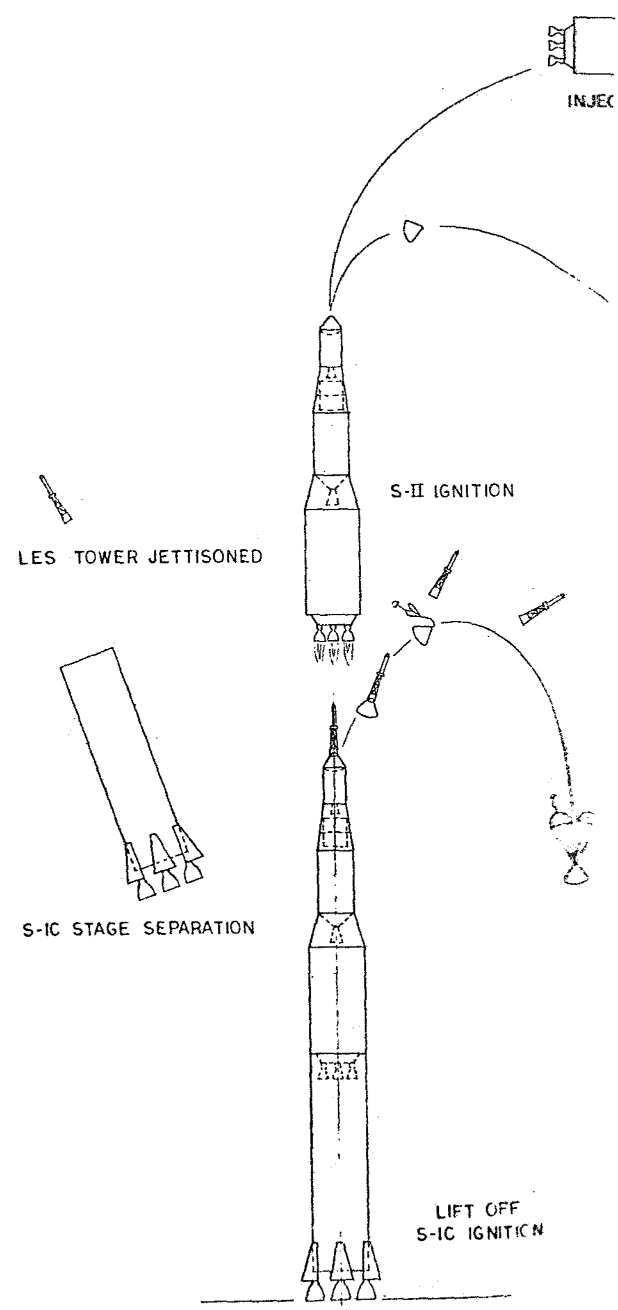
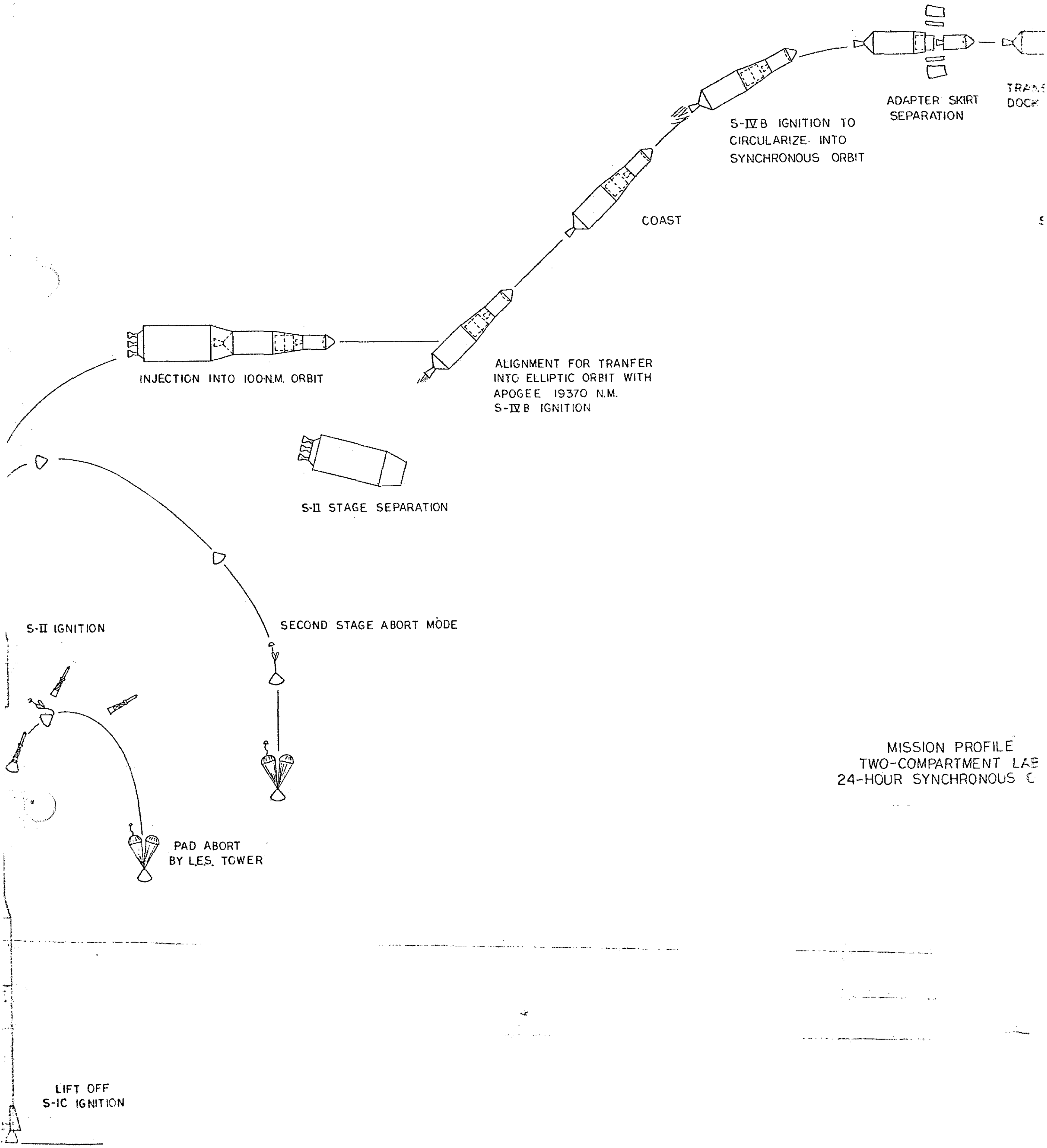
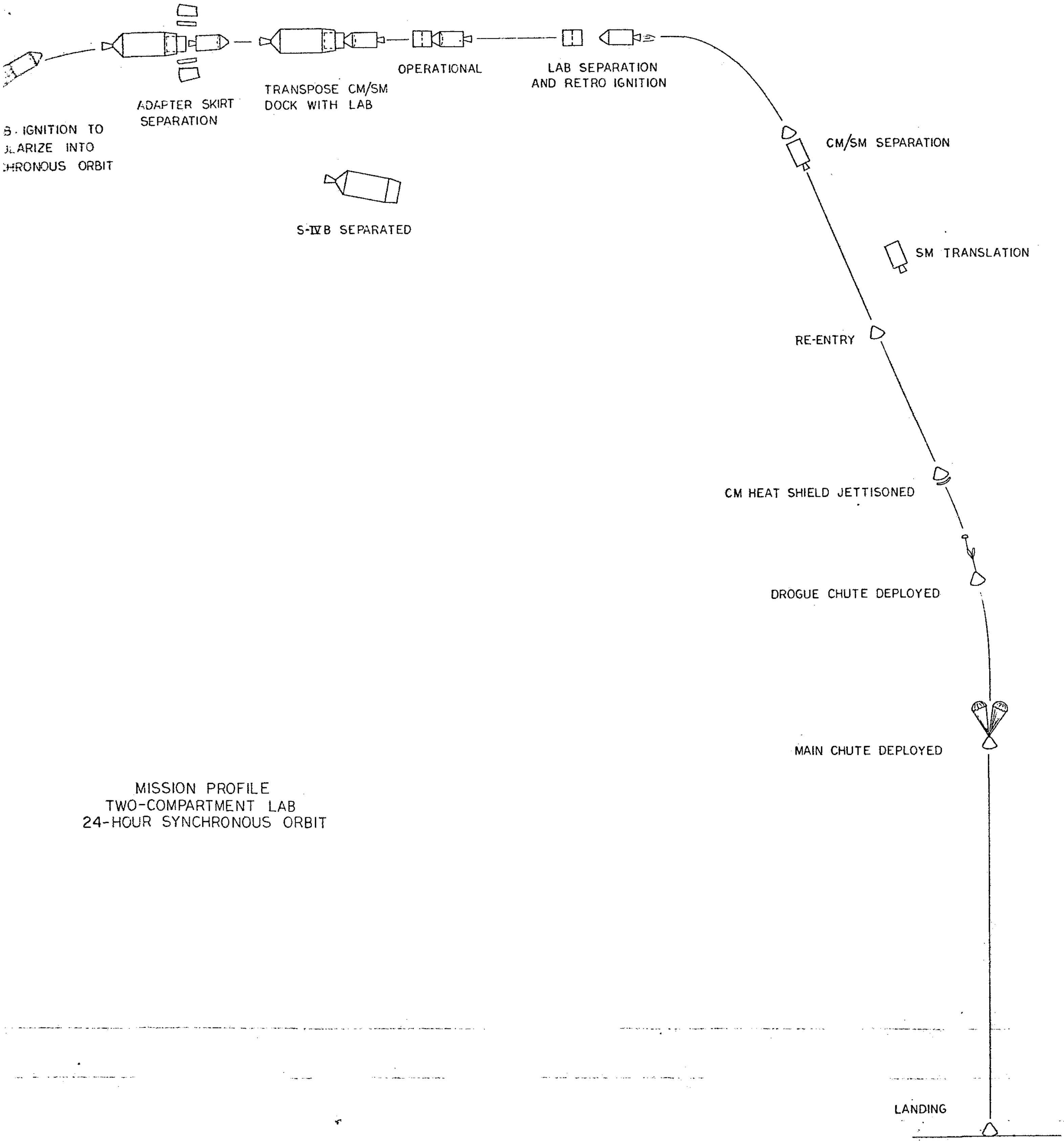


FIG. 3-5 MISSION PROFILE, INTERIM STATION

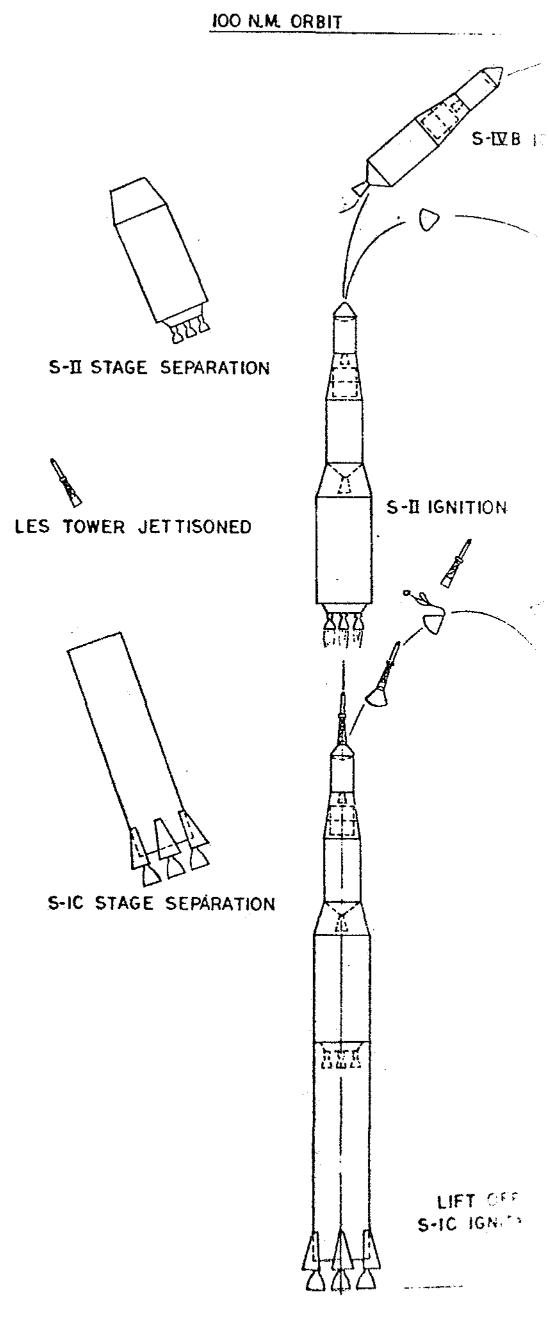


INJEC
S-II IGNITION
LES TOWER JETTISONED
S-IC STAGE SEPARATION
LIFT OFF
S-IC IGNITION


ADAPTER SKIRT SEPARATION
TRAN
DOCK
S-IVB IGNITION TO CIRCULARIZE INTO SYNCHRONOUS ORBIT
COAST
INJECTION INTO 100 N.M. ORBIT
ALIGNMENT FOR TRANFER INTO ELLIPTIC ORBIT WITH APOGEE 19370 N.M.
S-IVB IGNITION
S-II STAGE SEPARATION
S-II IGNITION
SECOND STAGE ABORT MODE
PAD ABORT BY L.E.S. TOWER
LIFT OFF
S-IC IGNITION
MISSION PROFILE
TWO-COMPARTMENT LAB
24-HOUR SYNCHRONOUS



MISSION PROFILE
TWO-COMPARTMENT LAB
24-HOUR SYNCHRONOUS ORBIT



100 N.M. ORBIT
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S-II STAGE SEPARATION
S-II IGNITION
LES TOWER JETTISONED
S-IC STAGE SEPARATION
LIFT
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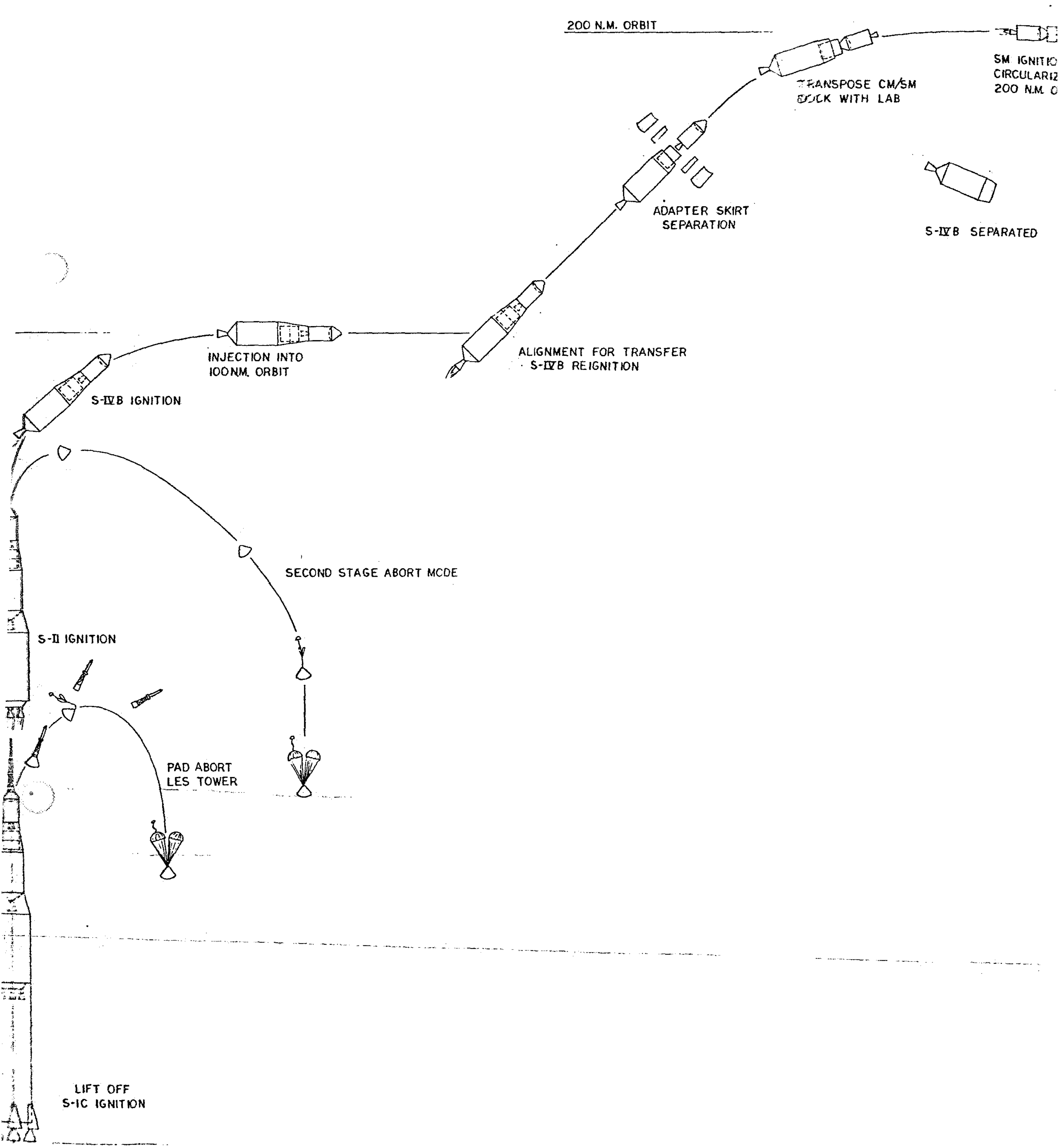


200 N.M. ORBIT
TRANSPOSE CM/SM
DOCK WITH LAB
ADAPTER SKIRT
SEPARATION
S-IVB SEPARATED
ALIGNMENT FOR TRANSFER
S-IVB REIGNITION
INJECTION INTO
100NM. ORBIT
S-IVB IGNITION
SECOND STAGE ABORT MODE
S-II IGNITION
PAD ABORT
LES TOWER
LIFT OFF
S-IC IGNITION

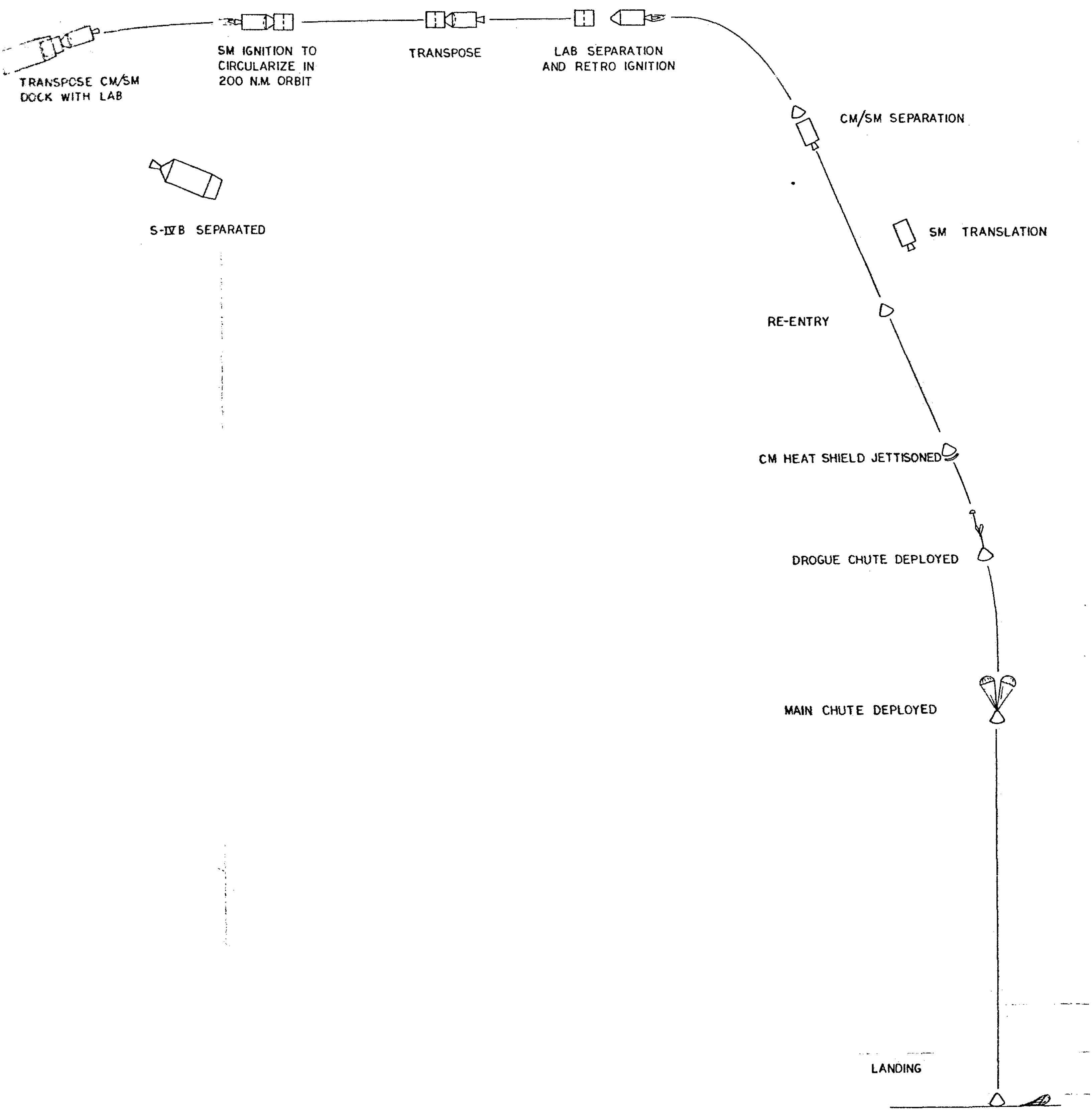
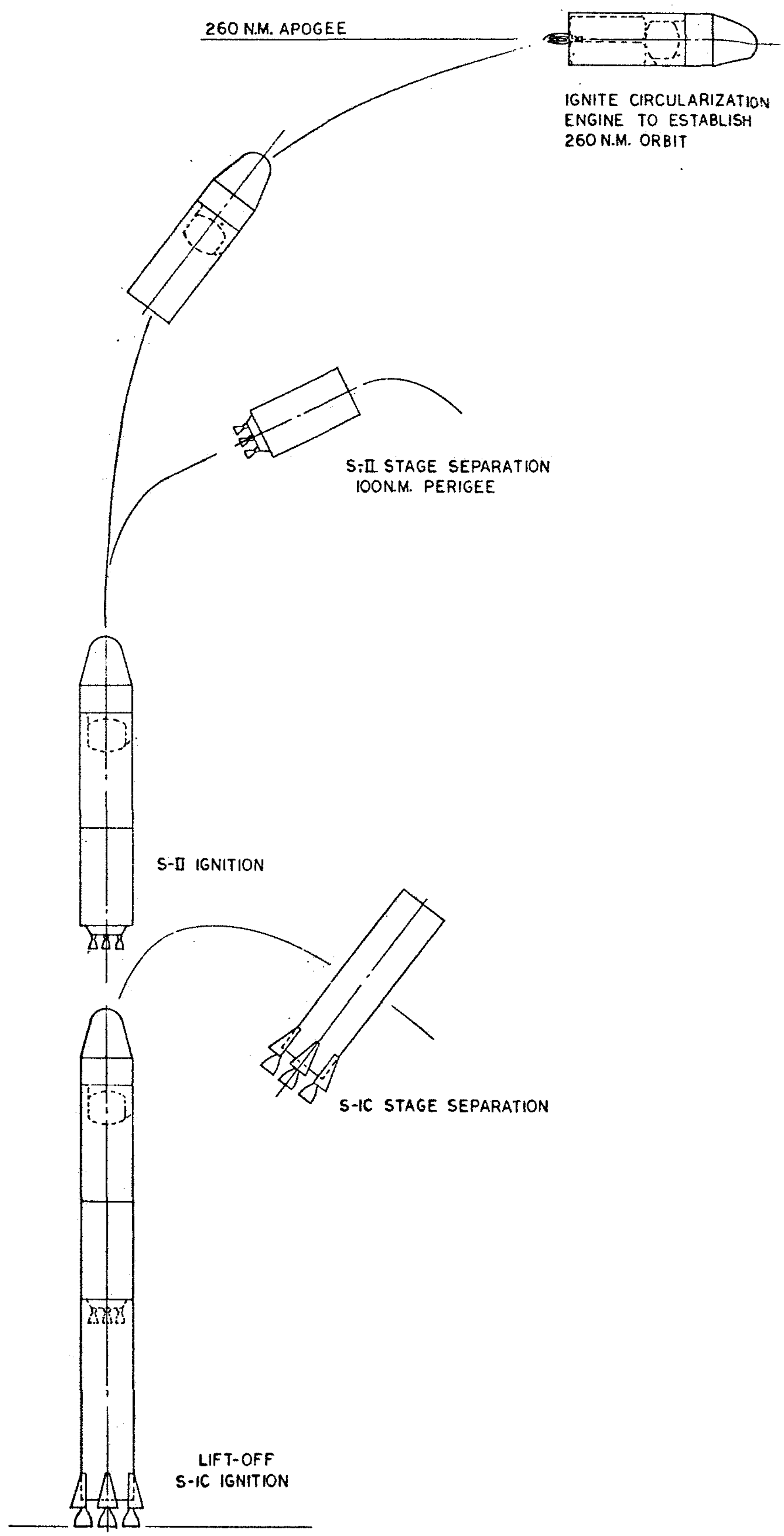
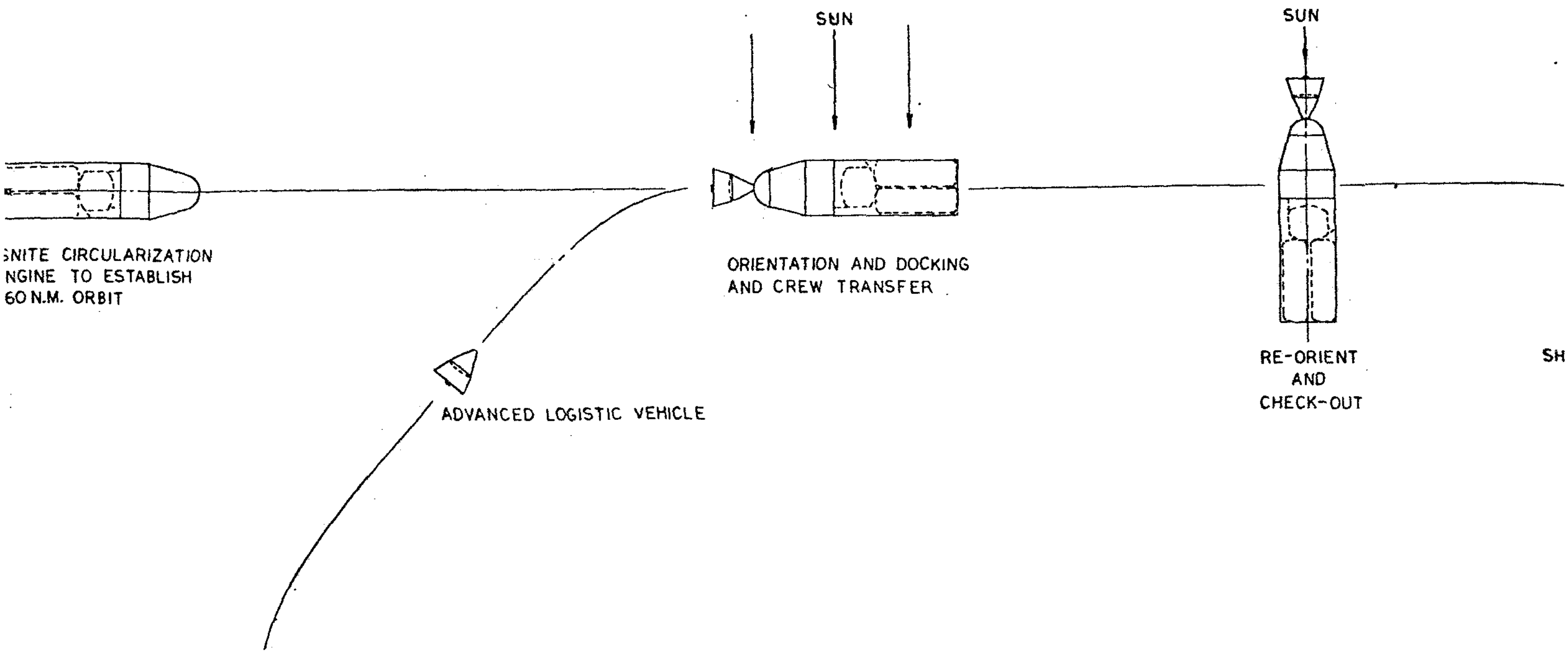


FIG. 3-7 MISSION PROFILE, TWO-COMPARTMENT POLAR ORBIT LABORATORY


260 N.M. APOGEE
IGNITE CIRCULARIZATION ENGINE TO ESTABLISH 260 N.M. ORBIT
S-II STAGE SEPARATION 100N.M. PERIGEE
S-II IGNITION
S-IC STAGE SEPARATION
LIFT-OFF
S-IC IGNITION



MISSION PROFILE
MULTI-MODULE LABOI
260-N.M. ORBIT

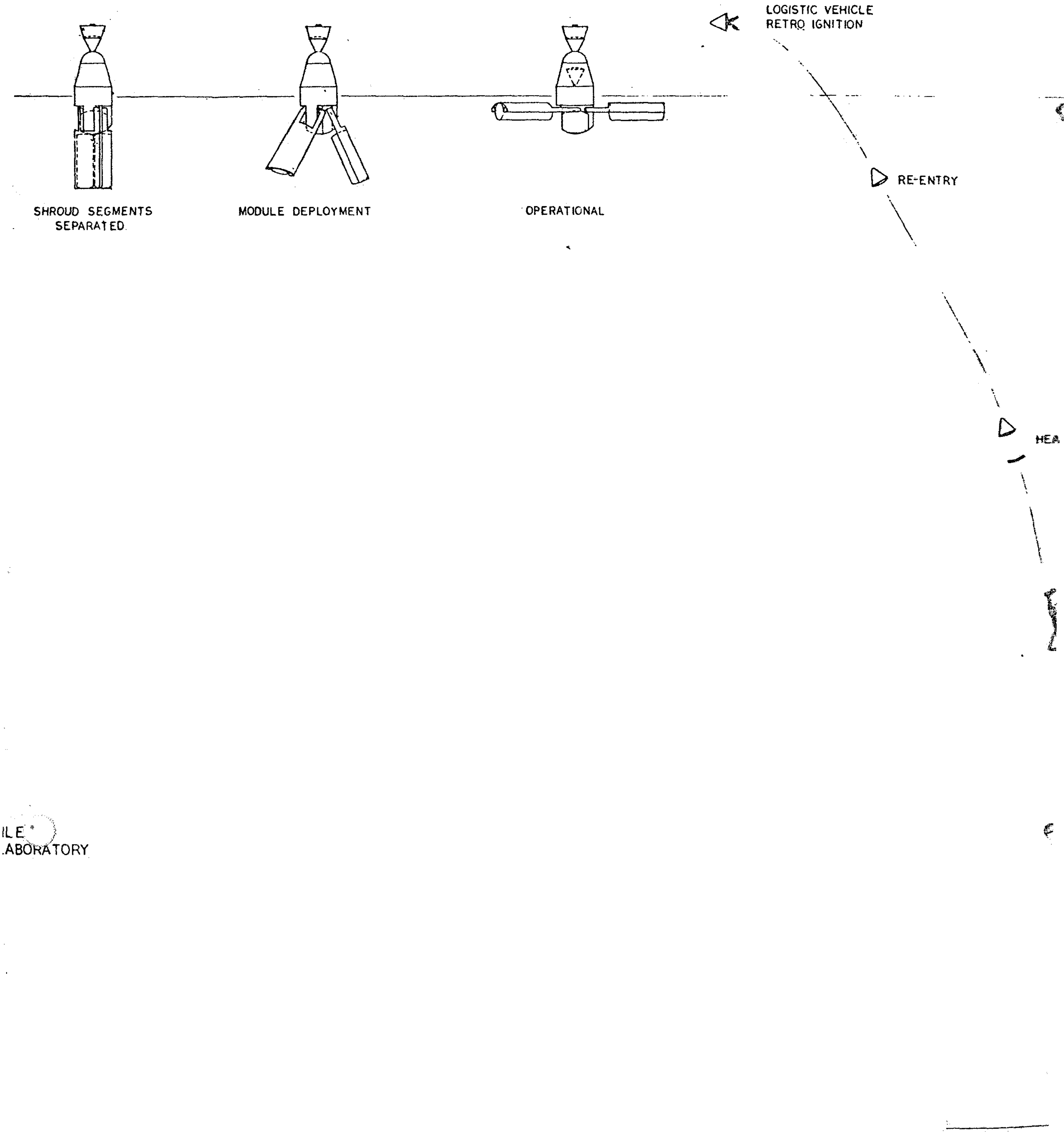
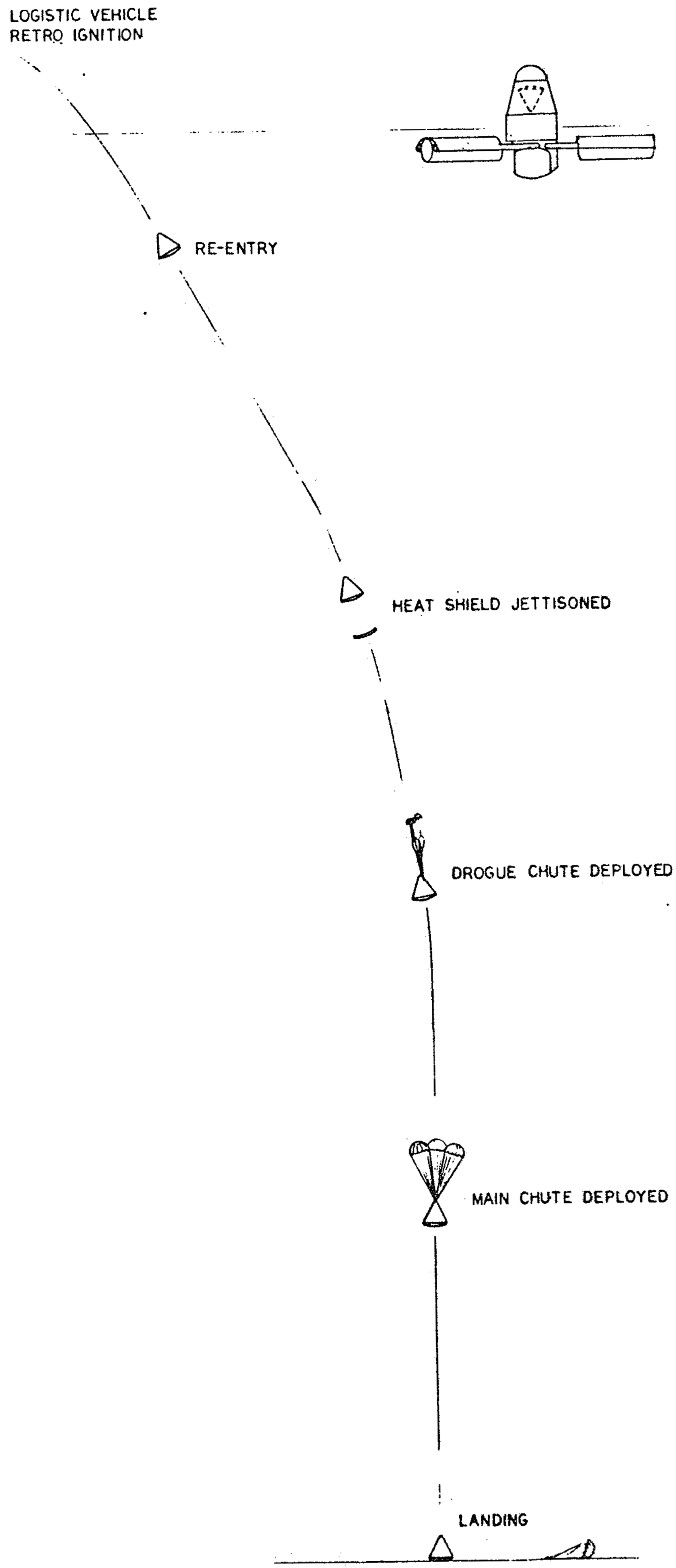


FIG. 3-8 MISSION PROFILE, OPERATIC



MISSION PROFILE, OPERATIONAL STATION

3.1 MODULAR CONFIGURATIONS

The Modular Multipurpose Space Station family is a series of stations starting with a single compartment module and progressing to a large multi-compartment, multi-module station. The design goal was to develop the series of space stations using a standard set of basic building blocks — the so-called modular concept. Stations of 183-in. and 260-in. diameter were to be studied - the 183-in. diameter because it fits the LEM adapter, and the 260-in. diameter because that is the size of the S-IVB stage of the launch vehicle. After studying the possibilities of the two sizes, the 183-in. diameter was selected because it fits within the LEM adapter and because the 260-in. diameter would require hammer-heading in the three radial module configuration. The study effort was therefore primarily concentrated on the 183-in. diameter stations and the following paragraphs (through Section 3.1.4) deal with it. The study results for the 260-in. diameter stations are presented in Section 3.1.5.

The stations considered for the modular concept are a One-Compartment Laboratory, a series of Two-Compartment Laboratories, an Interim Station consisting of six modular compartments, and an Operational Station utilizing three modules similar to the Interim Station module. The stations are shown in outline form in Fig. 3-9 and their characteristics are listed in Table 3-1.

Modular Concept

The basic building blocks for the modular concept underwent some modification as the study progressed. The original concept, shown in Fig. 3-10 consists of a barrel section, an upper dome, and a lower dome. The barrel section is a circular cylinder 183-in. in diameter and 90 in. long. It includes a curved floor of honeycomb construction and two hatches located so that they protrude into the joint line where an additional barrel section or end dome can be welded on. The wall structure consists of an integrally stiffened pressure shell of aluminum alloy with axially disposed fiberglass standoffs supporting the aluminized mylar insulation and the meteoroid shield.

The end domes are of semi-ellipsoidal double skin construction filled with foam. The upper dome contains three hatches and a support structure; the lower dome has one hatch, a support tube, and a curved floor of honeycomb construction.

A single-compartment laboratory is built up, in the original modular concept, by joining an upper and lower end dome. A two-compartment laboratory requires an upper and lower dome plus one cylindrical section. A six-compartment laboratory consists of an upper and lower dome plus five cylindrical sections.

The original modular concept had several features which needed improvement:

- The upper and lower end domes were different, an uneconomical feature.
- Hatch location in the cylindrical section complicated the joining of sections.
- Curved floors were unnecessary on zero gravity space stations.
- The floor in the lower dome was redundant from a pressure standpoint.

Most of the faults of the original modular concept were corrected in the second version. The dissimilar semi-ellipsoidal end domes are replaced with flat circular disks which serve as either floors or bulkheads. The bulkheads, which are of honeycomb construction, each have one centrally located hatch as shown in Fig. 3-11. The hatches in the cylindrical section are relocated so that they no longer protrude into the joint line. The bulkheads are supported by an interconnect assembly shown in Fig. 3-11 and 3-12. The interconnect assembly also provides access between floors of the two- and six-compartment stations. Structural details of the second modular concept are shown in Fig. 3-13. The role of the modular concept in the evolution of the Modular Multipurpose Space Station family is illustrated in Fig. 3-11.

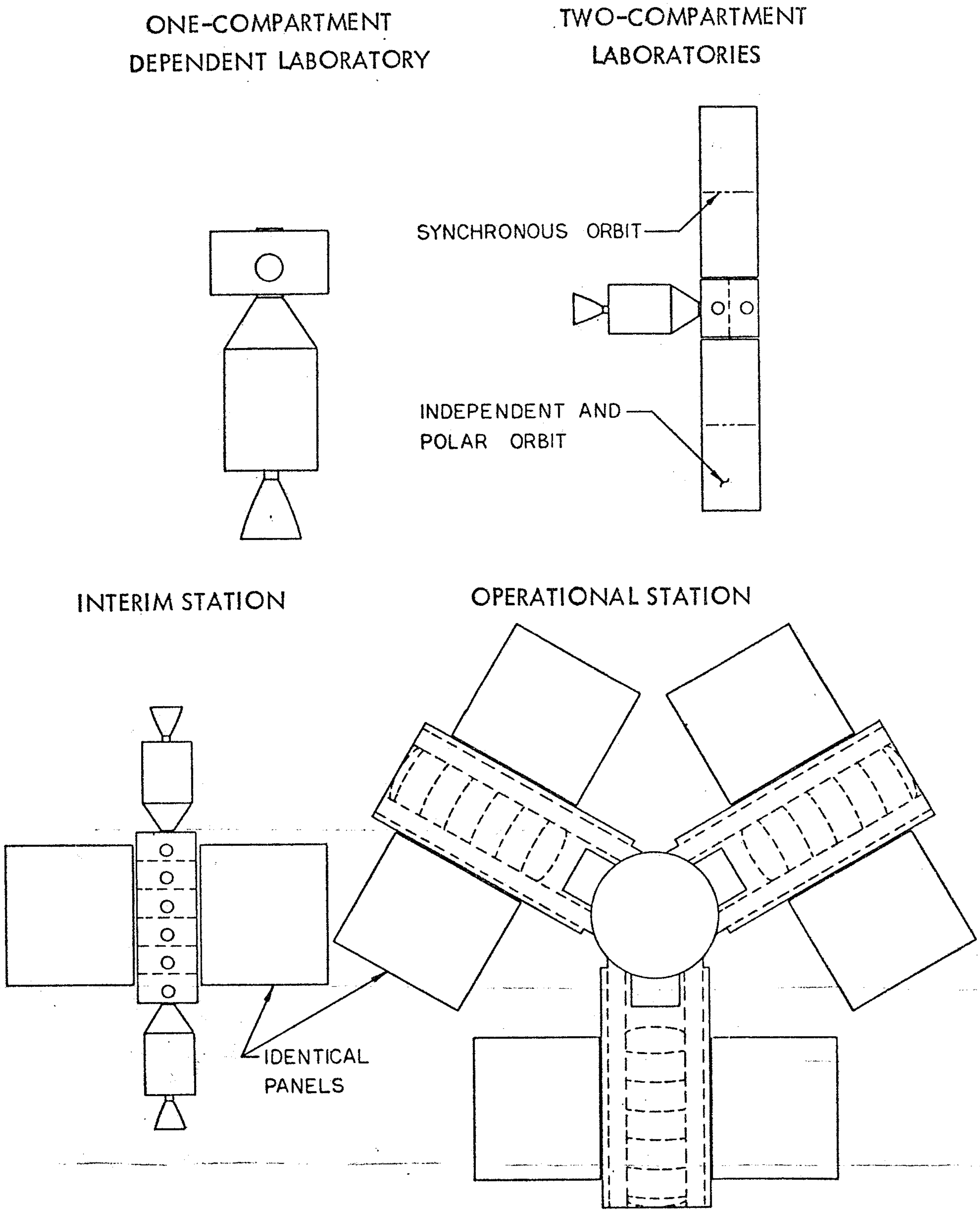
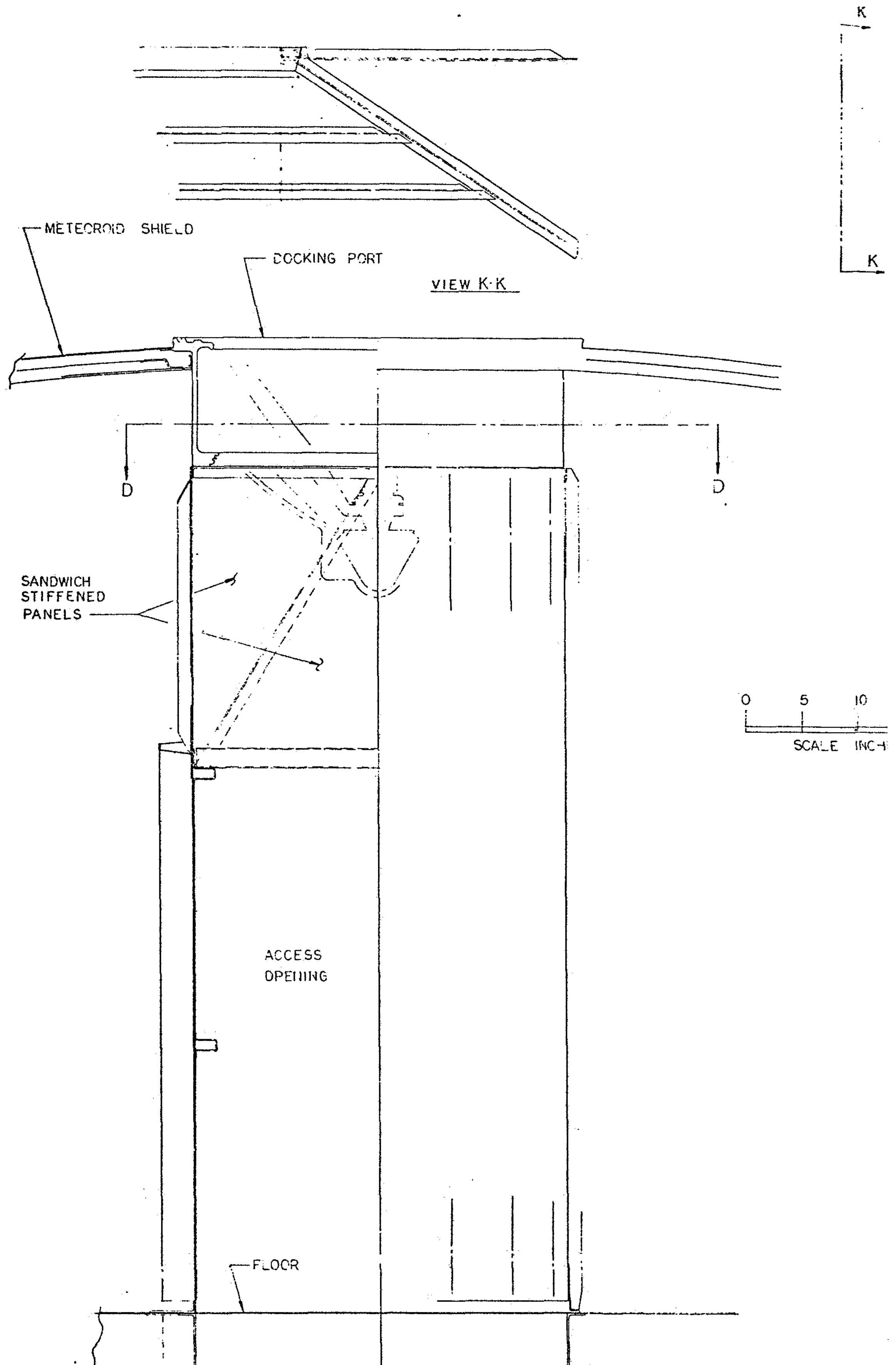


FIGURE 3-9 MODULAR MULTIPURPOSE SPACE STATION CONFIGURATIONS

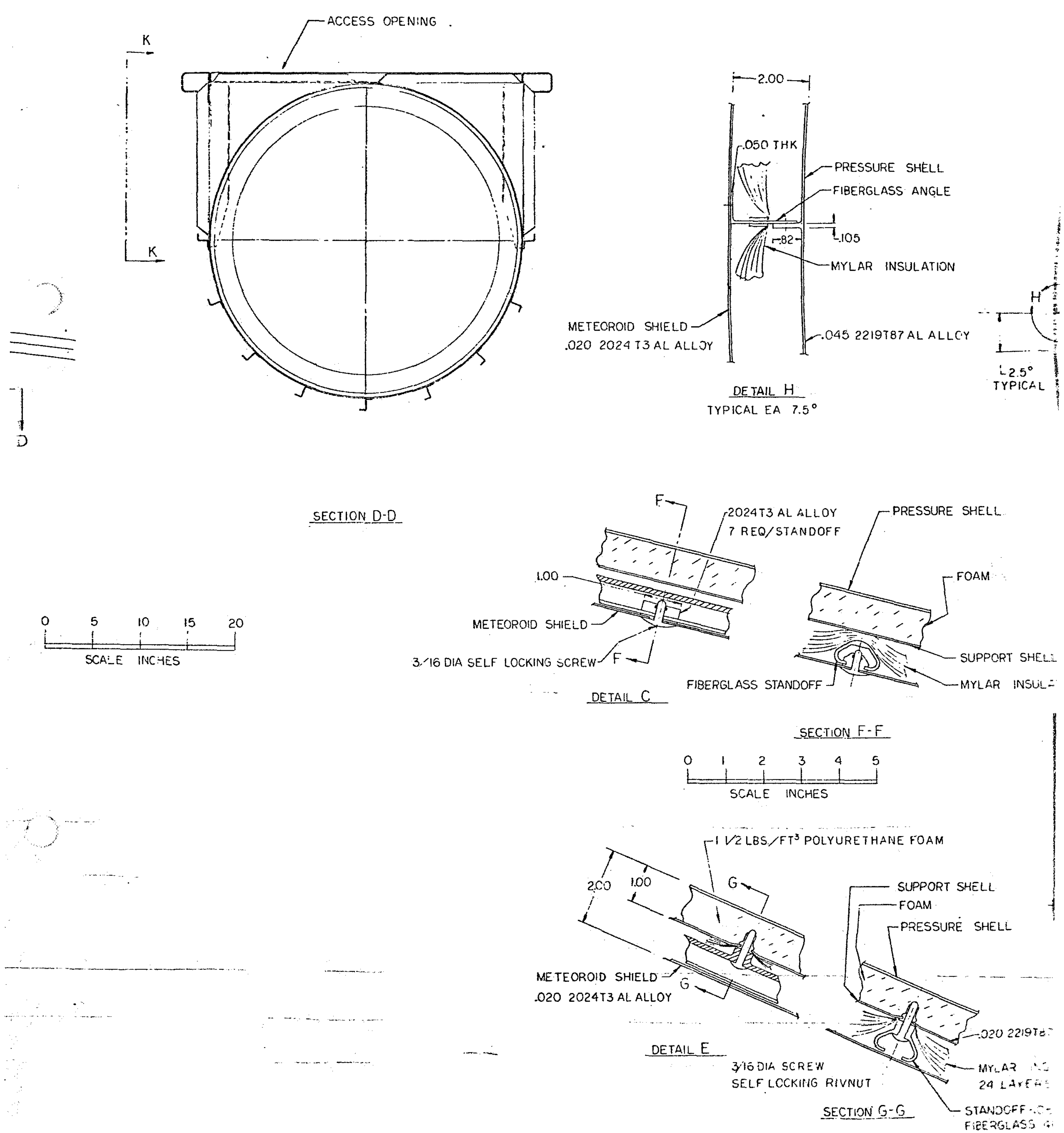
Table 3-1

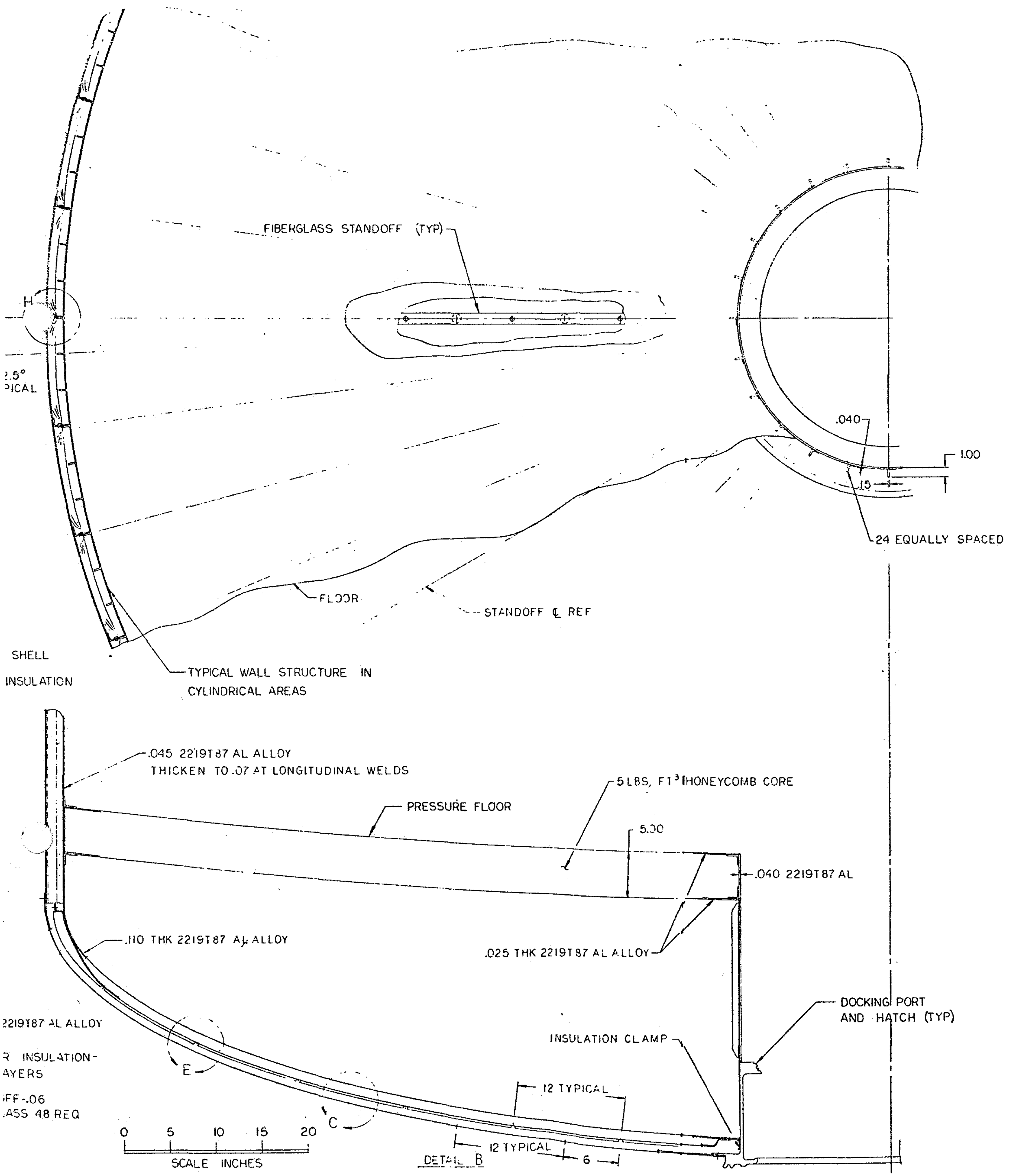
MODULAR MULTIPURPOSE SPACE STATION CHARACTERISTICS

CONFIGURATION / ITEM	ONE-COMPT. DEPENDENT LABORATORY	TWO-COMPARTMENT LABORATORIES			INTERIM STATION	OPERATIONAL STATION
		INDEPENDENT	POLAR ORBIT	SYNCHRONOUS ORBIT		
Orbital Altitude, n. miles	200	200	200	19,380	200	260
Orbital Inclination	28.5°	28.5°	90°	30°	28.5°	29.5°
Crew Size	3	6	3-6	3-6	6-9	Up to 36
Launch Vehicle	S-IB	S-IB	SV (3-stage)	SV (3-stage)	S-IB	SV (2-stage)
Mission Duration	45 days	Up to 1 Year	90 Days	90 Days	1-5 Years	5-10 Years
Crew Orbital Duration	45 Days	6 Months	90 Days	90 Days	6 Months	6 Months
Resupply Period	None	3 Months	None	None	3 Months	3 Months
Manned at Launch	Yes	Yes	Yes	Yes	No	No
Diameter of Compartment	183"	183"	183"	183"	183"	183"
Floor Pitch	N/A	90"	90"	90"	90"	90"
Floor Radius (Cylindrical)	Flat	Flat	Flat	Flat	Flat	717.5"
Structure	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Meteoroid Shielding	.99 PROBABILITY OF NOT MORE THAN ONE PENETRATION PER MONTH					
Airlock Provisions	Yes	Yes	Yes	Yes	Yes	Yes
Leakage Rate	8 lb/Day	7 lb/Day	7 lb/Day	7 lb/Day	10 lb/Day	24 lb/Day
Living and Sleeping Space	Apollo	Yes	Yes	Yes	Yes	Yes
Docking Provisions	Yes	Yes	Yes	Yes	Yes	Yes
Electric Power Source	Fuel Cell	Solar Cells	Solar Cells	Solar Cells	Solar Cells	Solar Cells
Power Level	1.5 kw	5-10 kw	5-10 kw	5-10 kw	10 kw	30 kw
Power Source Evolution	None	Isotope	Isotope	Isotope	Nuclear	Nuclear
ECS & Life Support	Open	Partially Closed	Partially Closed	Partially Closed	Partially Closed	Partially Closed
Environmental Req.	Pressure Suit/ Shirtsleeve	Pressure Suit/ Shirtsleeve	Shirtsleeve	Shirtsleeve	Shirtsleeve	Shirtsleeve
Atmospheric Constituency	O_2	O_2/N_2	O_2/N_2	O_2/N_2	O_2/N_2	O_2/N_2
Pressure Level, Total	5 psi	7 psi	7 psi	7 psi	7 psi	$3\frac{1}{2}$ to 14 psi



SECTION A-A ROTATED 90° COUNTER CLOCKWISE


ACCESS OPENING
K
K
D
SECTION D-D
0 5 10 15 20
SCALE INCHES
2.00
.050 THK
PRESSURE SHELL
FIBERGLASS ANGLE
.82
.105
MYLAR INSULATION
METEOROID SHIELD
.020 2024 T3 AL ALLOY
.045 2219T87 AL ALLOY
DETAIL H
TYPICAL EA 7.5°
H
2.5°
TYPICAL
F
2024T3 AL ALLOY
7 REQ/STANDOFF
1.00
METEOROID SHIELD
3/16 DIA SELF LOCKING SCREW
F
DETAIL C
PRESSURE SHELL
FOAM
SUPPORT SHELL
MYLAR INSUL
FIBERGLASS STANDOFF
SECTION F-F
0 1 2 3 4 5
SCALE INCHES
1 1/2 LBS/FT³ POLYURETHANE FOAM
2.00
1.00
G
METEOROID SHIELD
.020 2024T3 AL ALLOY
G
DETAIL E
SUPPORT SHELL
FOAM
PRESSURE SHELL
.020 2219T8
MYLAR
24 LAYERS
3/16 DIA SCREW
SELF LOCKING RIVNUT
STANDOFF
FIBERGLASS
SECTION G-G



FIBERGLASS STANDOFF (TYP)
H
2.5°
TYPICAL
.040
1.00
.15
24 EQUALLY SPACED
FLOOR
STANDOFF ℄ REF
SHELL
INSULATION
TYPICAL WALL STRUCTURE IN CYLINDRICAL AREAS
.045 2219T87 AL ALLOY
THICKEN TO .07 AT LONGITUDINAL WELDS
5 LBS, FT³ HONEYCOMB CORE
PRESSURE FLOOR
5.00
.040 2219T87 AL
.110 THK 2219T87 AL ALLOY
.025 THK 2219T87 AL ALLOY
DOCKING PORT
AND HATCH (TYP)
2219T87 AL ALLOY
R INSULATION-
AYERS
FF-.06
ASS 48 REQ
INSULATION CLAMP
E
C
12 TYPICAL
12 TYPICAL
6
0 5 10 15 20
SCALE INCHES
DETAIL B

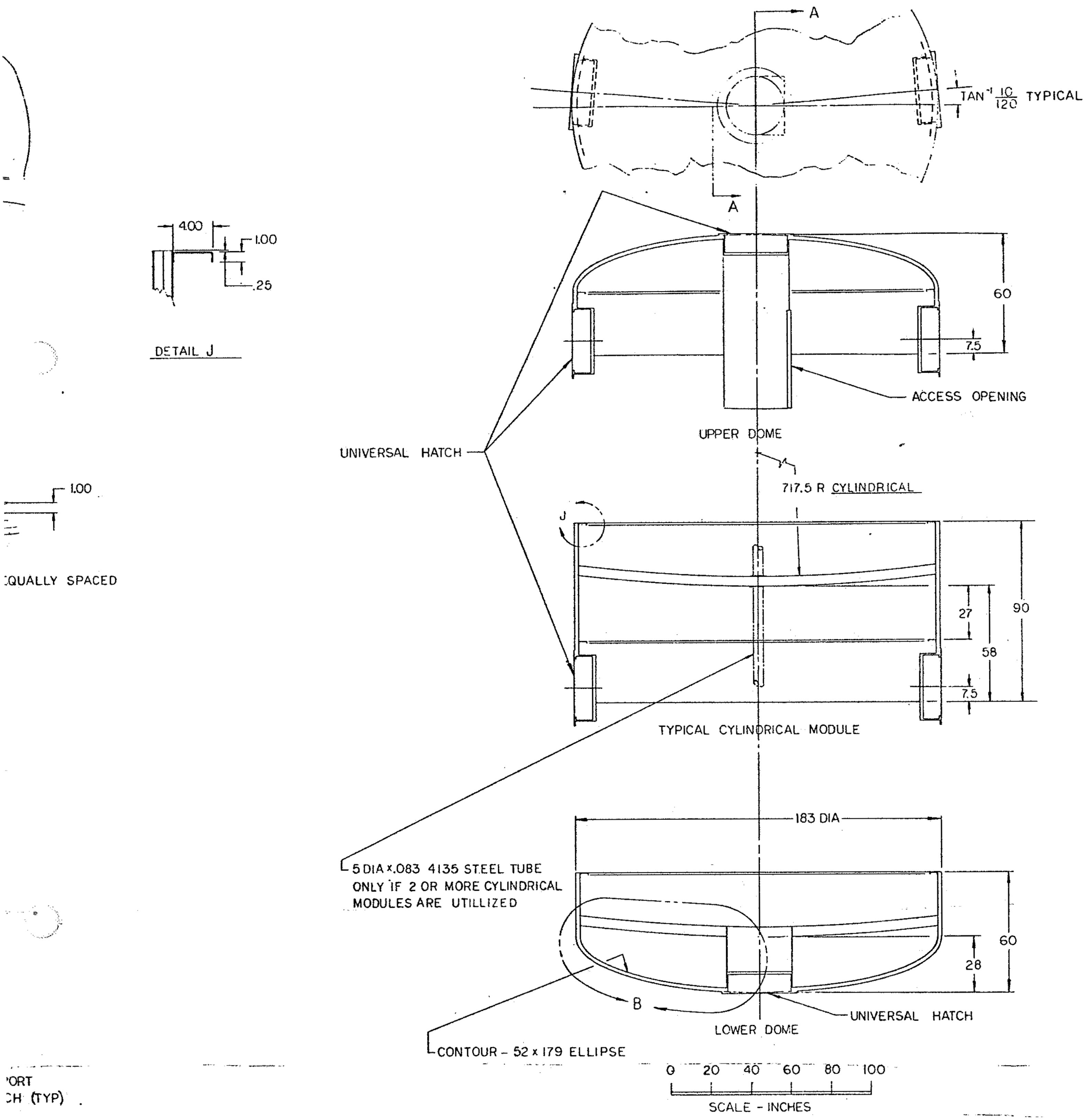
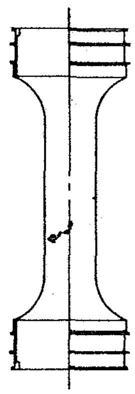
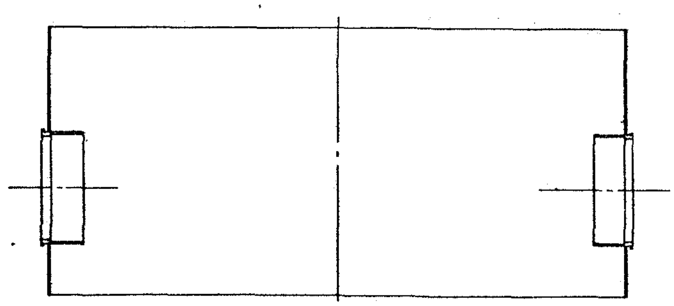


FIG. 3-10 STRUCTURE, ORIGINAL MODULAR CONCEPT

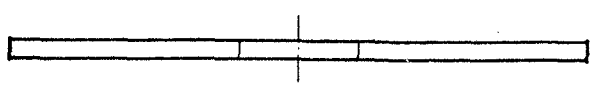


FLOOR INTERCONNECT ASSEMBLY

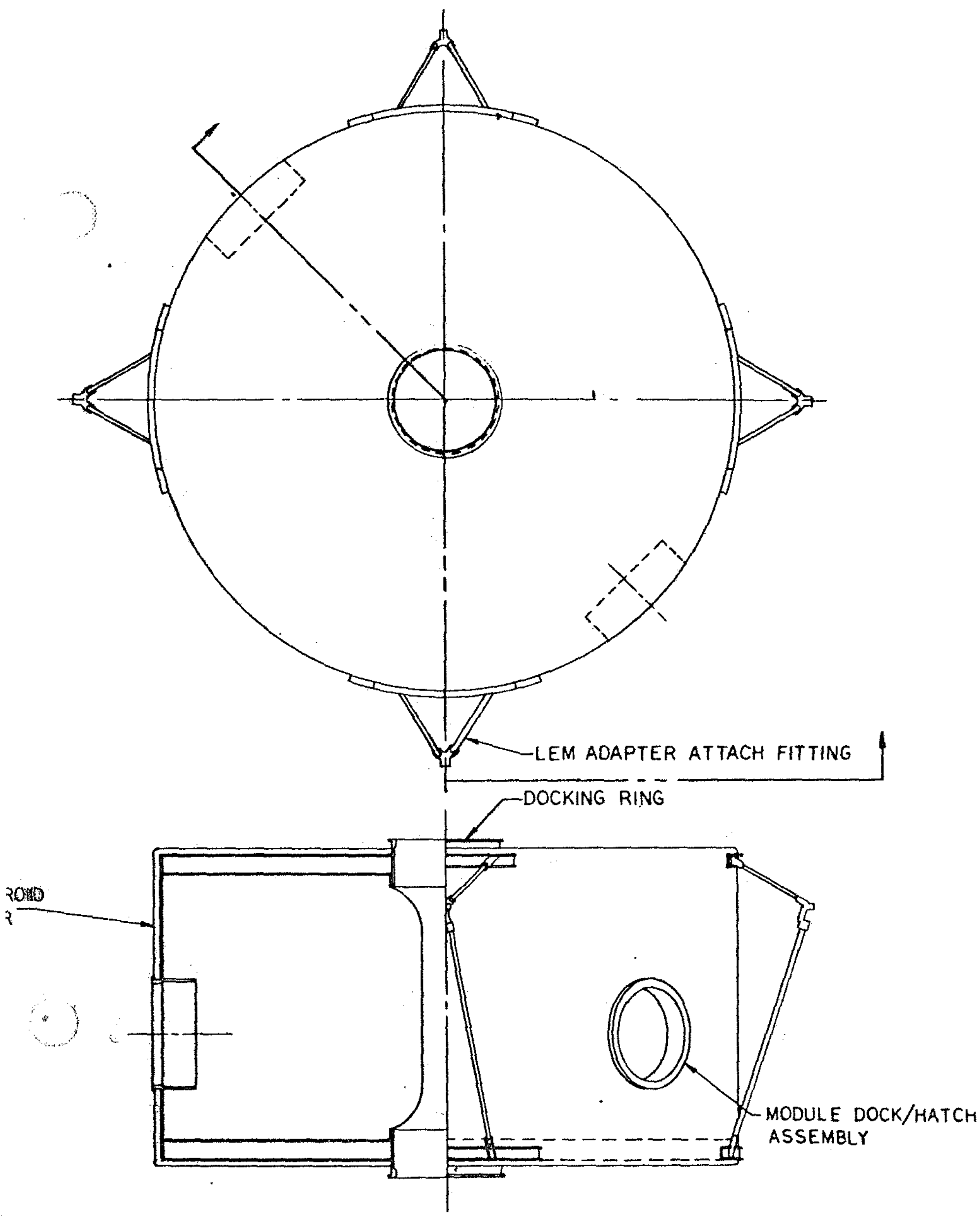
METEOROID
BUMPER



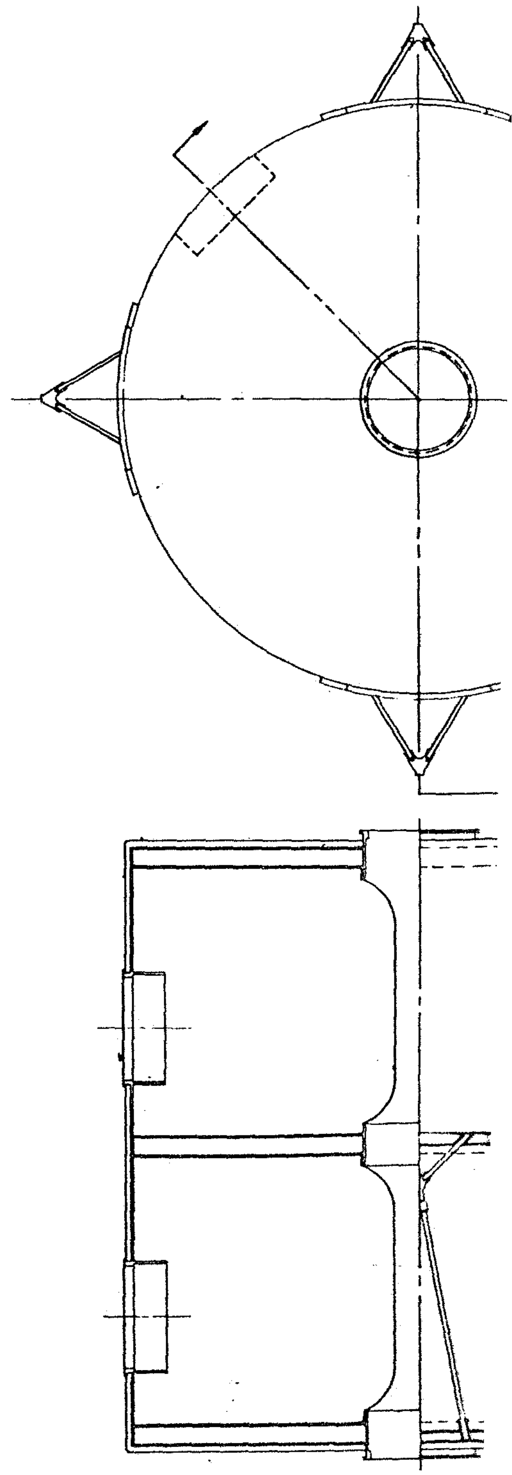
MODULE BARREL ASSEMBLY



PRESSURE FLOOR ASSEMBLY



SINGLE COMPARTMENT LABORATORY ASSEMBLY



DOUBLE COMPARTMENT LABOR

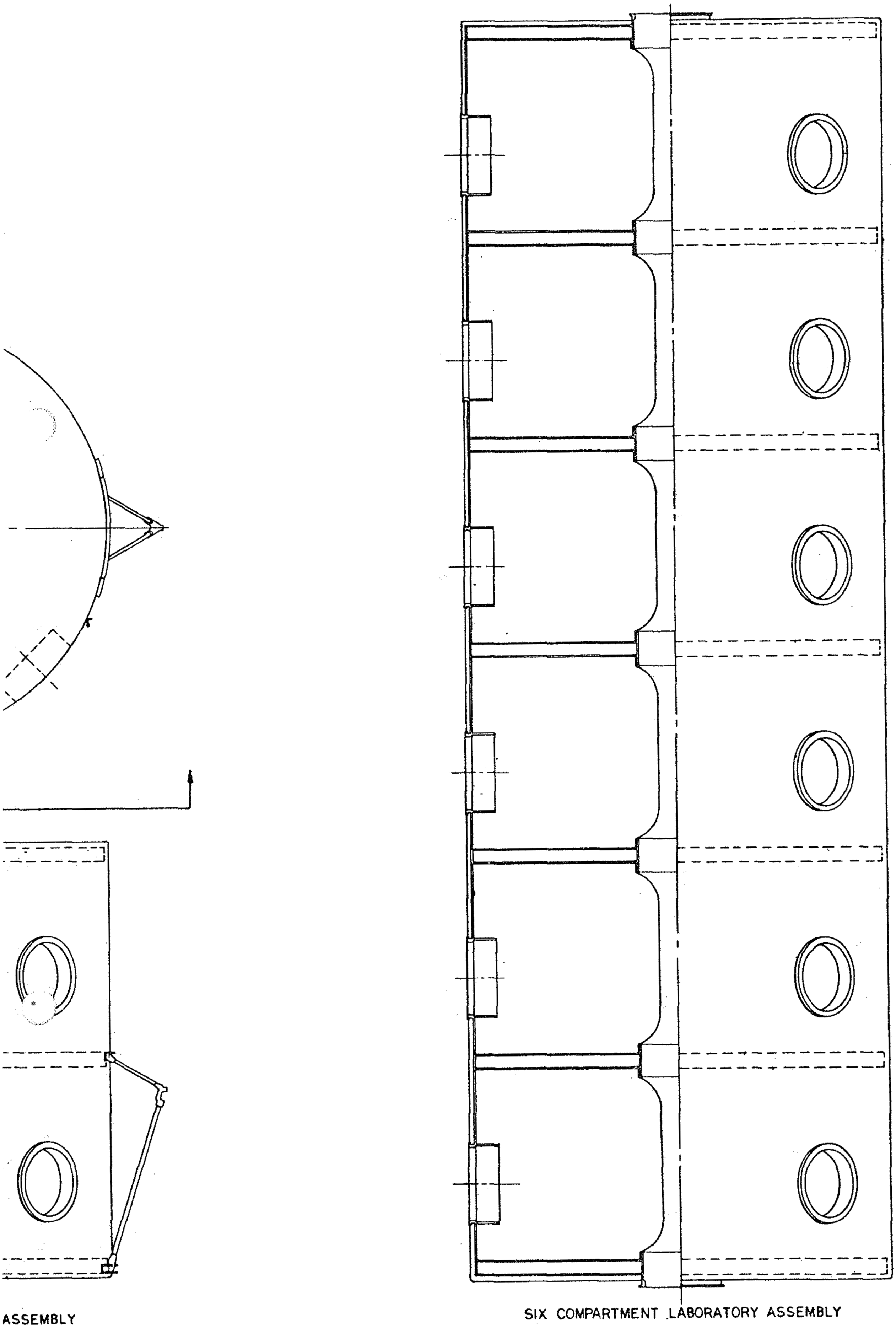
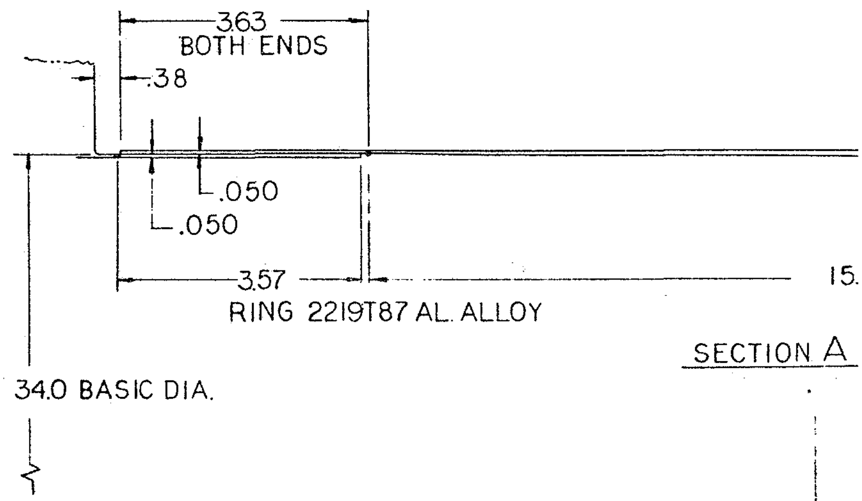
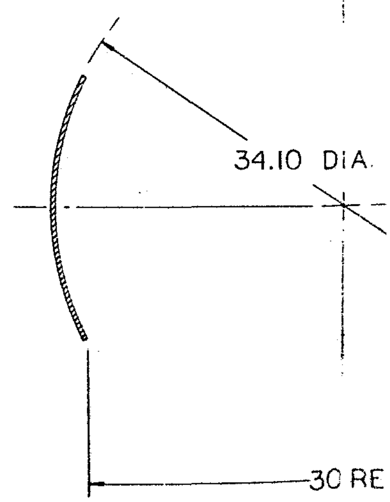


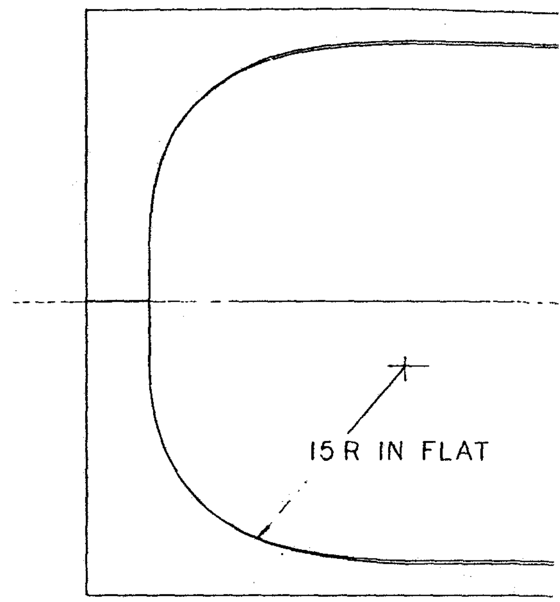
FIG. 3-11 SEQUENTIAL EVOLUTION, SECOND MODULAR CONCEPT

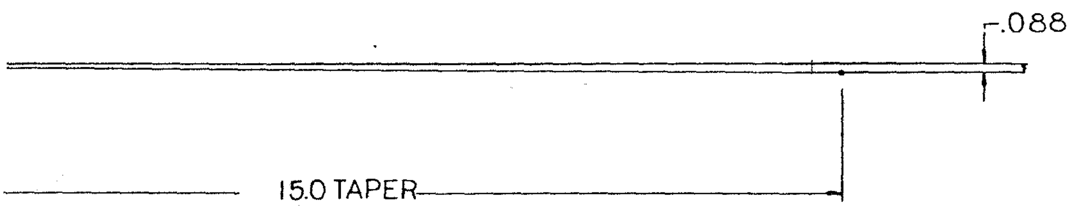


SECTION A

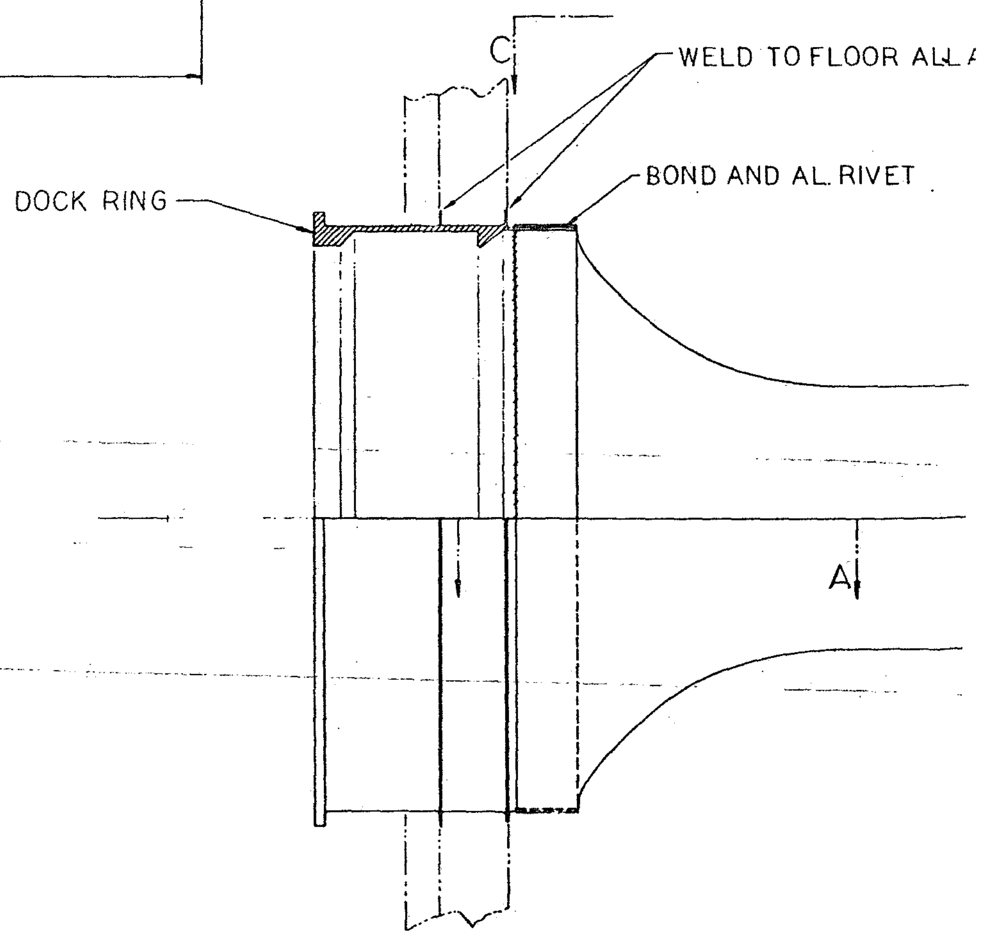


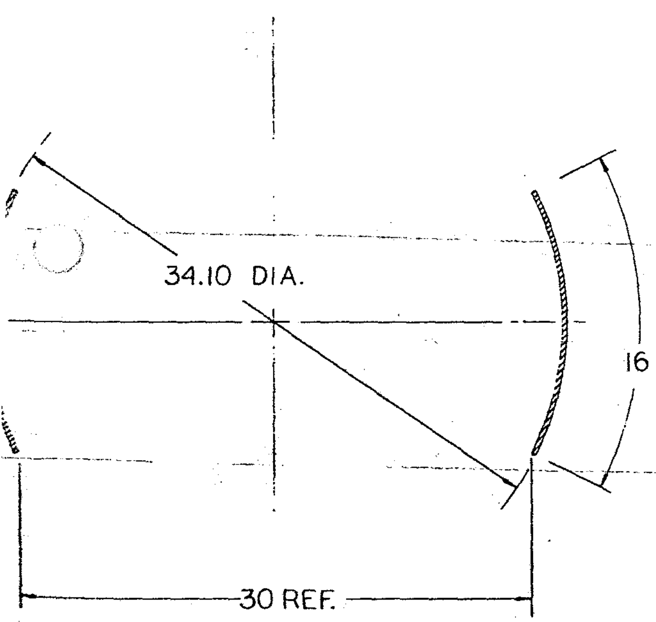
SECTION





SECTION A-A





SECTION B-B

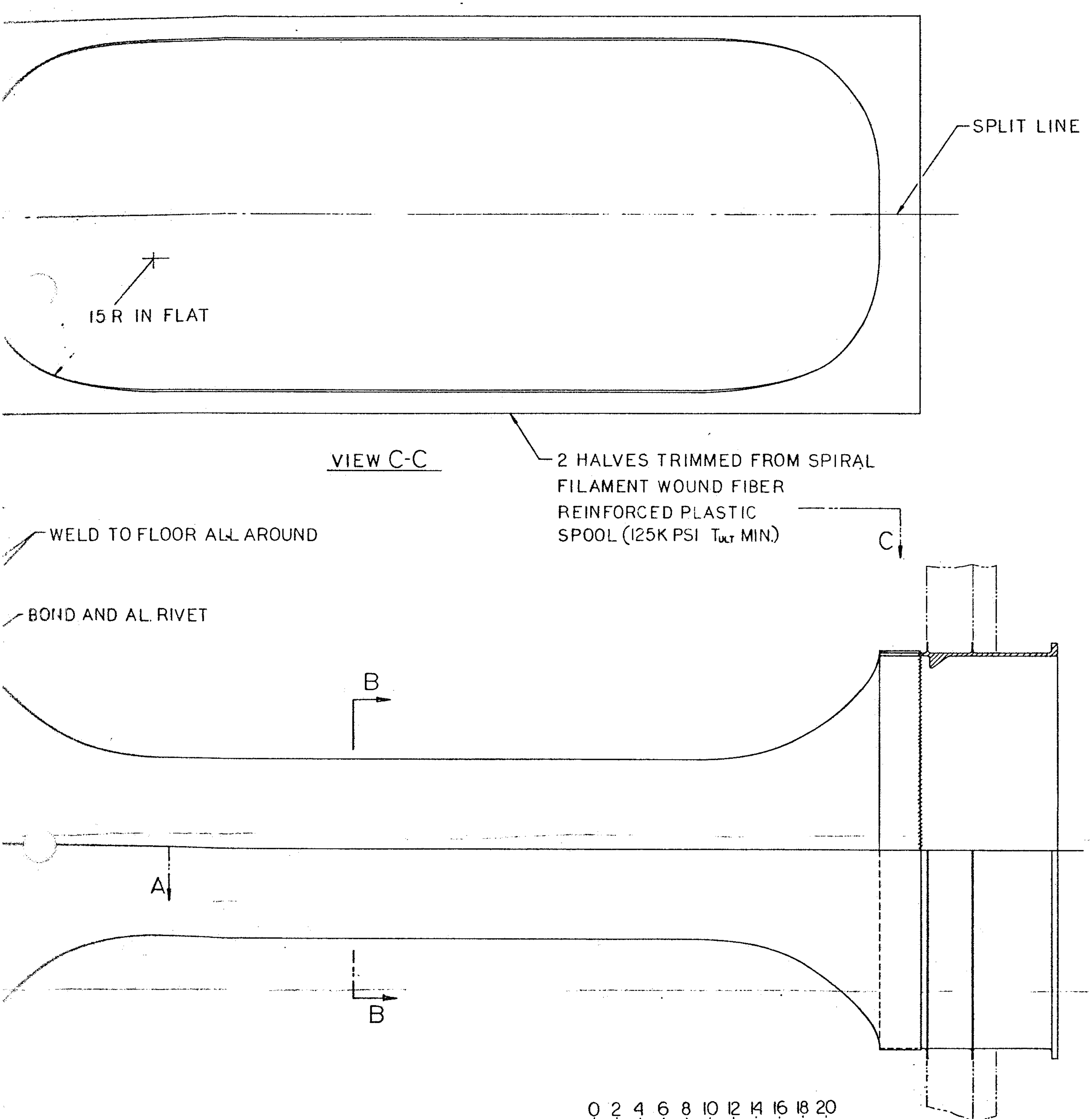
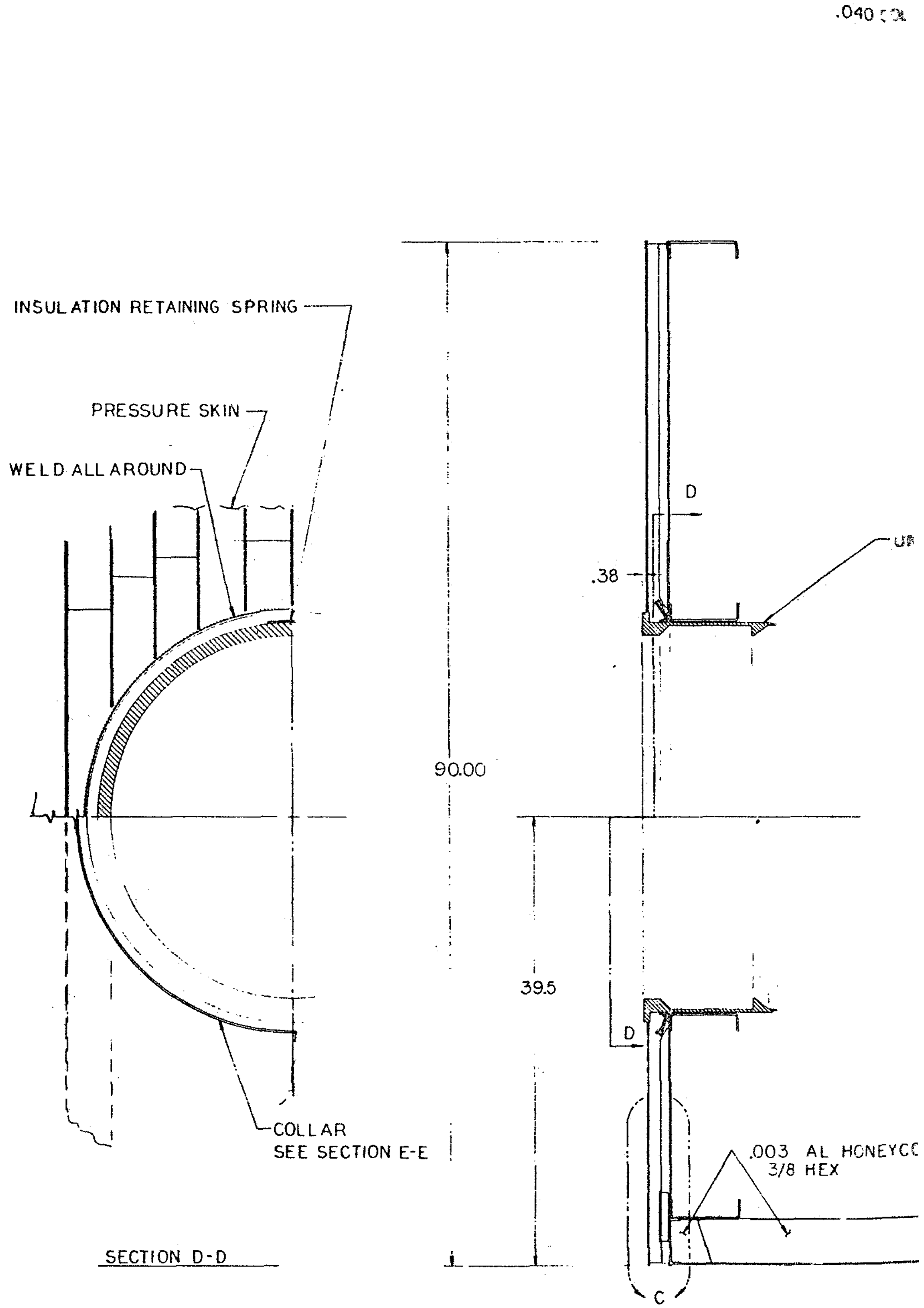
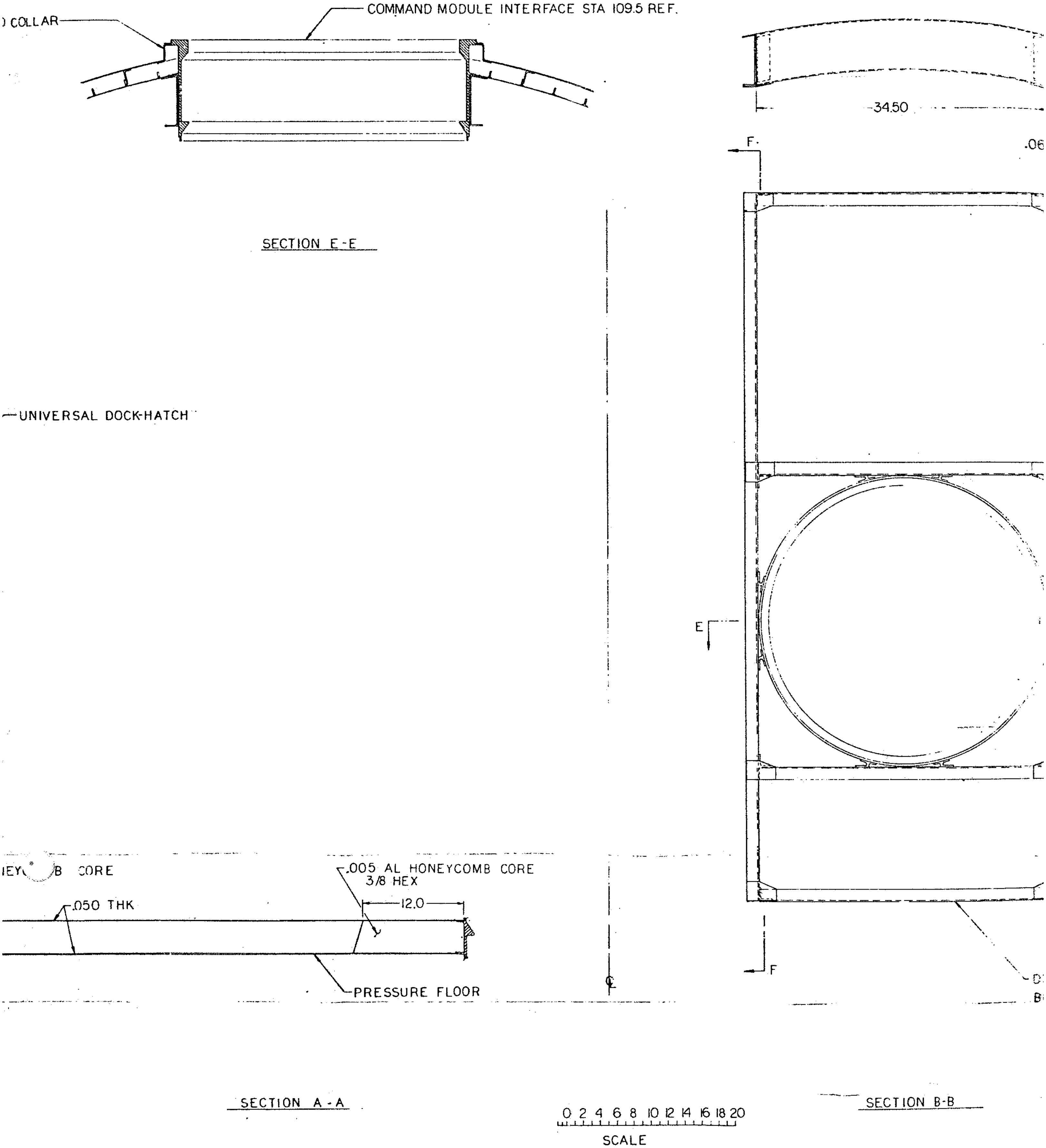


FIG. 3-12 INTERCONNECT ASSEMBLY MODULE FLOOR


.040
INSULATION RETAINING SPRING
PRESSURE SKIN
WELD ALL AROUND
COLLAR
SEE SECTION E-E
SECTION D-D
90.00
39.5
.38
D
D
C
.003 AL HONEYC
3/8 HEX



COLLAR
COMMAND MODULE INTERFACE STA 109.5 REF.
SECTION E-E
-34.50
F
.06
UNIVERSAL DOCK-HATCH
E
CORE
.005 AL HONEYCOMB CORE
3/8 HEX
12.0
.050 THK
PRESSURE FLOOR
℄
F
SECTION A-A
0 2 4 6 8 10 12 14 16 18 20
SCALE
SECTION B-B

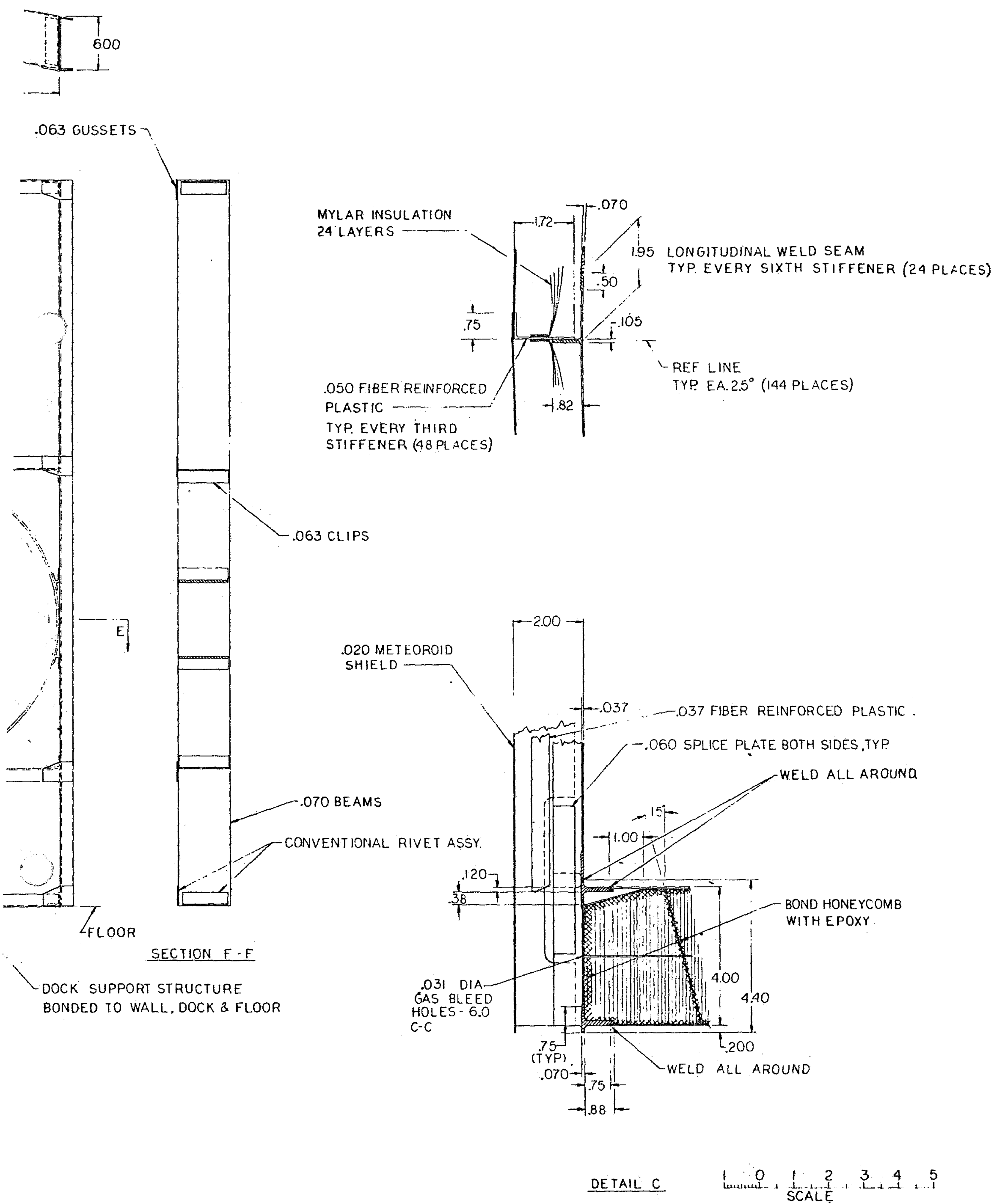

600
.063 GUSSETS
MYLAR INSULATION
24 LAYERS
.070
1.72
1.95 LONGITUDINAL WELD SEAM
TYP. EVERY SIXTH STIFFENER (24 PLACES)
.50
.75
.105
REF LINE
TYP. EA. 2.5° (144 PLACES)
.050 FIBER REINFORCED
PLASTIC
TYP. EVERY THIRD
STIFFENER (48 PLACES)
.82
.063 CLIPS
E
2.00
.020 METEOROID
SHIELD
.037
.037 FIBER REINFORCED PLASTIC
.060 SPLICE PLATE BOTH SIDES, TYP.
WELD ALL AROUND
.070 BEAMS
15°
1.00
CONVENTIONAL RIVET ASSY.
.120
.38
BOND HONEYCOMB
WITH EPOXY
FLOOR
SECTION F-F
DOCK SUPPORT STRUCTURE
BONDED TO WALL, DOCK & FLOOR
.031 DIA
GAS BLEED
HOLES - 6.0
C-C
4.00
4.40
.75
(TYP)
.200
.070
.75
.88
WELD ALL AROUND
DETAIL C
0 1 2 3 4 5
SCALE

FIG. 3

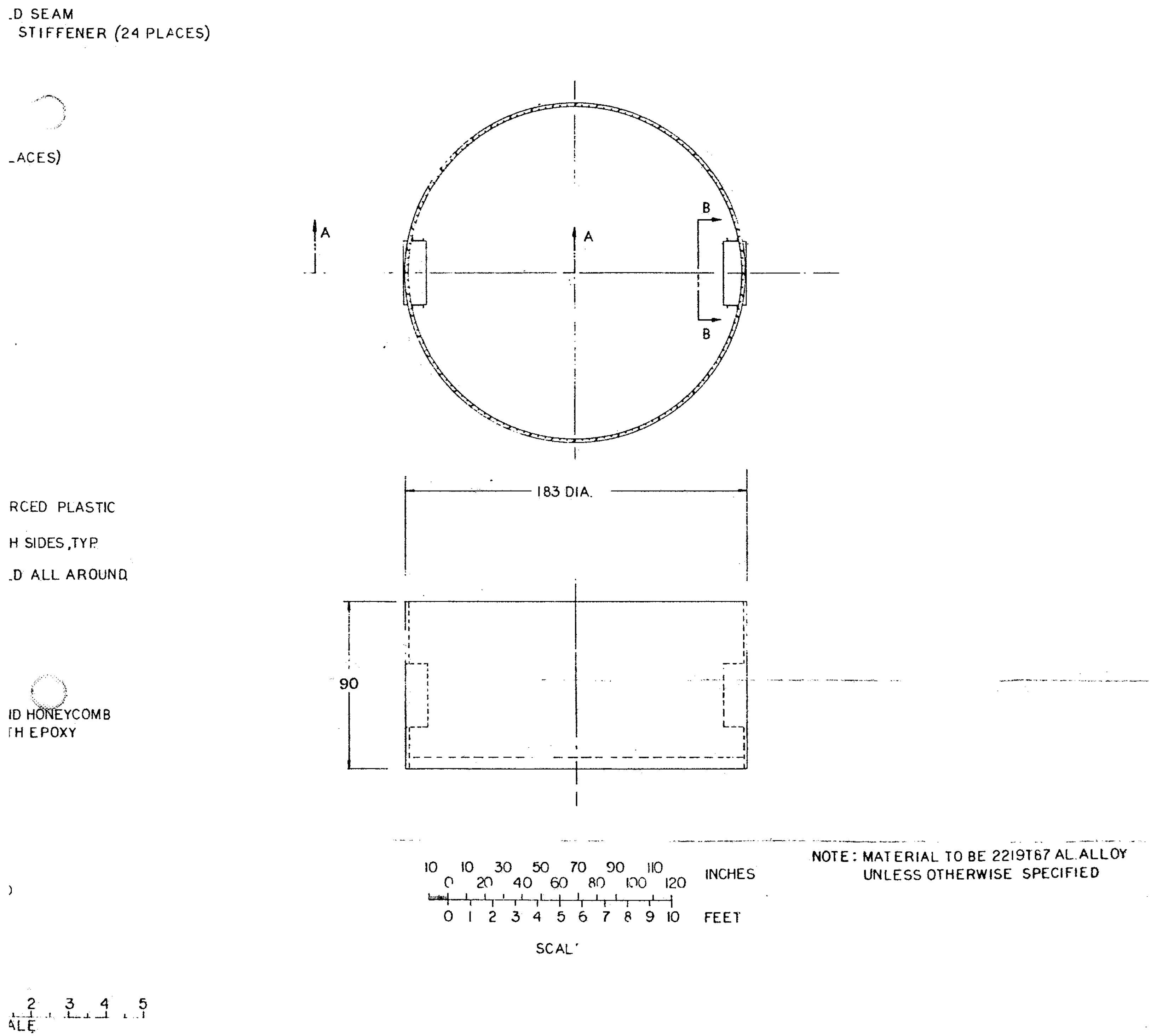


FIG. 3-13 STRUCTURAL DETAILS, SECOND MODULAR CONCEPT

The final version of the modular concept is similar to the second version except that the honeycomb bulkhead construction is changed to an integral beam design because the beam design proves to be lighter.

The One- and Two-Compartment Laboratories are supported within the LEM adapter during the launch sequence. Figure 3-14 shows three design concepts for supporting these laboratories in the LEM adapter. The truss support proves to be the lightest in weight and is therefore the recommended design.

A universal hatch design suitable for use as a docking port, window, attachment point or wall penetration for external experiments or inter-compartment hatch, is a feature of all versions of the modular concept. Figure 3-15 shows structural details and applications of this hatch. When the hatch is used as a docking facility, the cover is domed to provide clearance for an Apollo docking probe. There are internal and external locking handles so that the hatch can be operated from either side. The cover is completely removable and is stowed above the hatch. A variety of units may be attached to these hatch openings including external experiment packages, external air locks, and telescopes.

An inter-compartment hatch is used on the two- and six-compartment configurations. This hatch opening is the same diameter as the side hatch, and sealing is accomplished in the same manner. A handle on each side of the flat cover operates four locking dogs simultaneously. The cover, when opened, hinges and translates against the floor interconnect structure and is held in this position by a magnetic catch.

3.1.1 One-Compartment Laboratory

Two versions of the One-Compartment Laboratory module were designed; one with honeycomb and one with integral beam bulkheads. Figure 3-16 shows the module with honeycomb bulkheads. This design retains the floor interconnect assembly. Fig. 3-17 shows the final version of the laboratory module. The bulkheads are constructed of integrally stiffened structural segments; the upstanding integral legs become beam caps of 8-in. deep beams. The webs are made of fiberglass. Aluminized mylar insulation and meteoroid shielding are installed above the load-carrying webs. The ceiling structure has the beams on the inside so that they may be used for the mounting of consoles and equipment within the module. The bulkheads are supported by an optional arrangement utilizing four tubes that pick up beam intersection points in the integral floor. This optional arrangement is discussed further in Section 3.3.2.5. The floors contain an access opening that is used during construction and for the installation of equipment.

The One-Compartment Laboratory module is mounted inside the LEM adapter for the launch sequence as shown in Fig. 3-14. Adapter skirt separation is the same as for the LEM vehicle. The transposition and docking of the CSM combination to the compartment is similar to docking to the LEM. Reentry of the command module is similar to that of the Apollo mission.

3.1.2 Two-Compartment Laboratories

The Two-Compartment Laboratory modules are assembled by joining two cylindrical elements containing floor bulkheads and then capping the open end with a flat bulkhead that serves as a ceiling for the upper element. Figure 3-18 shows a version of the module with either honeycomb bulkheads or integral beam bulkheads, although the integral beam design is recommended. The floor interconnect assemblies shown can be strengthened so that they can be used as airlocks. The truss-type supports for mounting the module in the LEM adapter are identical to those used on the One Compartment Laboratory.

The rectangular solar array (the preferred design) for the Two Compartment Laboratories is shown in Fig. 3-19. The panels are stowed on the sides of the modules within the LEM adapter. An alternate circular panel design is illustrated in Fig. 3-20. Here the panels are stowed underneath the modules at the lower end of the LEM adapter. The panels illustrated in Fig. 3-19 and 3-20 are sized for the Independent and Polar Orbit Laboratories; those for the Synchronous Orbit Laboratory would have half the area shown.

3.1.3 Interim Space Station

The Interim Space Station, shown in Fig. 3-21, requires six cylindrical elements for the module assembly with the integral beam bulkhead construction. Floor interconnect assemblies, omitted for clarity in the drawing, may be either the type shown in Fig. 3-12 or an airlock type.

The adapter between the station and the launch vehicle is illustrated, and solar cell arrays are shown stowed and deployed. The cone angle of the adapter is the same as that used for the LEM adapter. The solar panels are articulated so that the station may be earth oriented and the solar arrays sun oriented. A mechanism for articulation of the solar panels is illustrated in Section F-F of Fig. 3-21 . Shaped charges are positioned for adapter separation. The module stiffener rings shown in the adapter area are considered to be part of the adapter structure, i.e., they are not common to all sections of the module.

3.1.4 Operational Space Station

The Operational Space Station is the end product in the family of stations which utilize the modular concept as a design approach. The guidelines used to define this station depart from those used to define the other stations of the family and as a result, some changes in the modular concept as developed to this point are required:

- The maximum compartment pressure in the Operational Station is 14.7 psia rather than 7 psia. This change dictates a return to semi-elliptical end domes on the modules because of weight considerations.
- The station will have artificial gravity capability. Curved floors are therefore desirable in order to produce a floor surface normal at all points to the artificial gravity vector.
- The station will have access tubes on both sides of the modules. Floor interconnect assemblies are therefore unnecessary.

Figure 3-22 shows a module of the Operational Station with semi-elliptical domes, curved floors, and supporting tubes between the floors. Details of the area of the hub-module joint are shown on Fig. 3-23. This rotating joint, mounted on a ball bearing, permits 90-deg rotation of the module during station deployment. The deployment cable and mechanism are shown as are the attachments that are made after the station has been deployed. These attachments are sealed over after they are made. The electrical and fluid connections across the joint are shown; most of these connections are made after deployment. One cable assembly is connected prior to launch for electrical circuits that are to be monitored prior to and during deployment.

Figure 3-24 shows two concepts of the use of modular components for hub configurations for the Operational Station. One method provides an upper docking turret with accommodations for five logistic vehicles. Unloading can be accomplished directly into a storage area by use of the short transfer tunnel. The zero-g lab is made up of four modular compartments. The centrifuge consists of portions of a module and can handle up to twelve men at a time. The other method illustrated shows a lower docking turret that accommodates five logistic vehicles. Cargo unloading is by direct transfer to a storage area. The zero-g lab is located on the upper end of the hub and is composed of three modular compartments. The centrifuge is similar to the one previously described. The lower docking turret arrangement gives a shorter overall launch configuration length.

3.1.5 Study of 260-in. Diameter Stations

An investigation was made of modular compartment space stations utilizing a diameter of 260 inches. Figure 3-25 shows the sequential evolution of the one, two and four-compartment stations. These compartments utilize a wall and floor structure similar to that used in the final design of the 183-in. diameter modular compartment station.

The floor and wall configuration of the 260-in. diameter modular compartment is shown on Fig. 3 -26. The floor structure is composed of integrally stiffened skin and 12-in. deep built-up beams. A 90-in. pitch between floors is maintained which provides a 78-in. floor-to-ceiling height. Four posts tie the floors together near the center. A 33.2 x 69.5 in. rectangular opening is provided in the floor for access during fabrication of the stations.

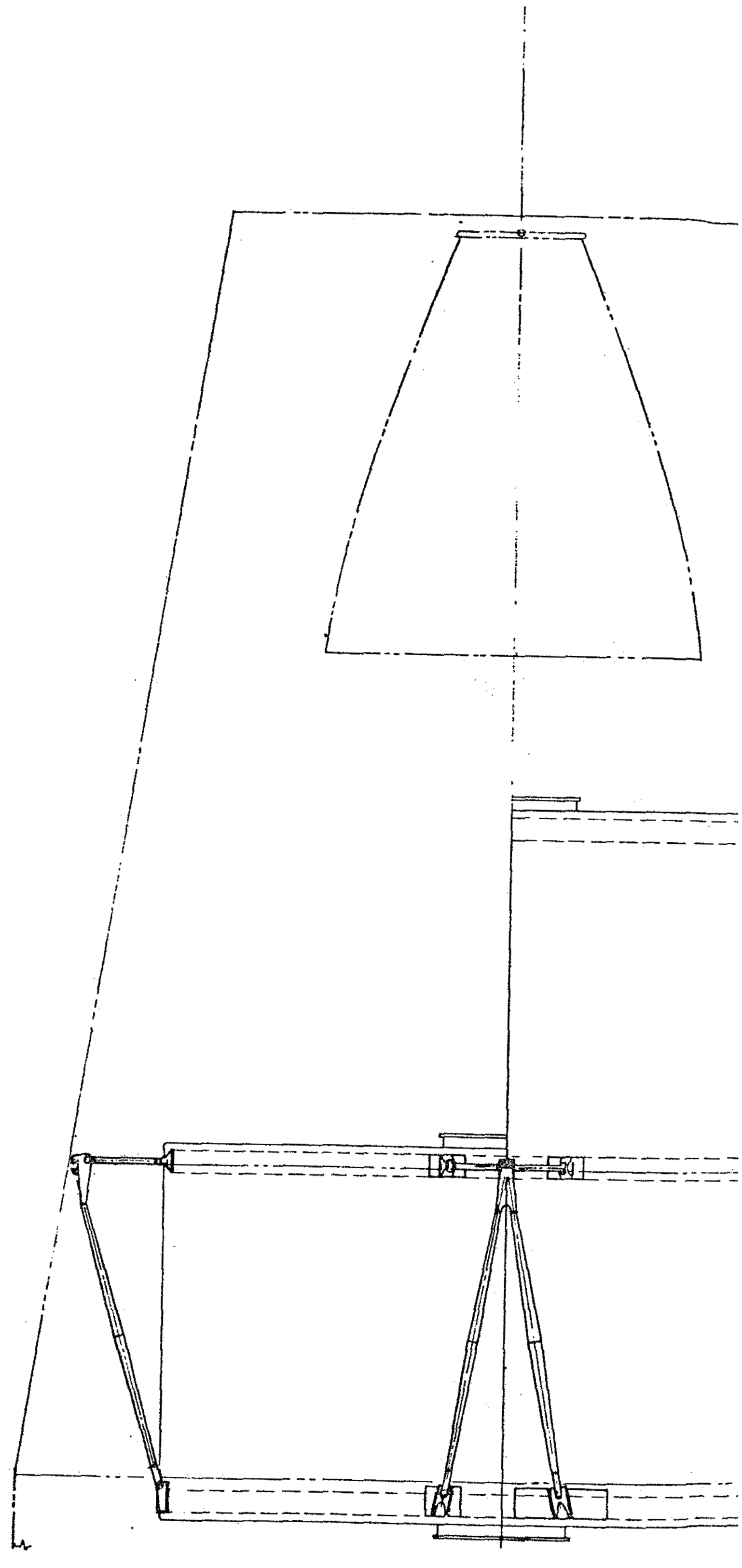
The Operational Modular Multipurpose Space Station with 260-in. diameter modules is shown on Fig. 3 -27. Each of the three modules is structurally the same and consists of four compartments with curved floors and domed ends. Two access tubes provide dual routes to the hub, which has similar domed ends with docking ports in the center. The hub is 260-in. diameter also and portions of the module wall structure can be utilized in the design. The hub contains a zero g laboratory, storage space and a centrifuge. The launch shroud is not shown on this drawing although portions of it would be retained for use as meteoroid shielding.

The one- and two-compartment laboratories use the Saturn IB launch vehicle and the compartments mount directly to the instrument package on the S-IVB stage. The LEM adapter is empty except for some experiments externally mounted on the laboratory compartment. The mission profile of these two laboratories would require the LEM adapter to be completely separated from the launch vehicle prior to command module docking with the station, and then separation of the station from the S-IVB stage. Modifications to the LEM adapter and S-IVB stage would be necessary.

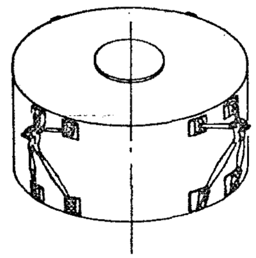
The four compartment laboratory is launched unmanned by Saturn IB. After launch to 28.5 deg, 200-n.mile apogee, the station separates from the S-IVB stage and the orbit is circularized by use of an onboard propulsion subsystem.

The two special mission, polar or synchronous orbit flights are handled by a two-compartment station mounted on a Saturn V launch vehicle, and launched manned.

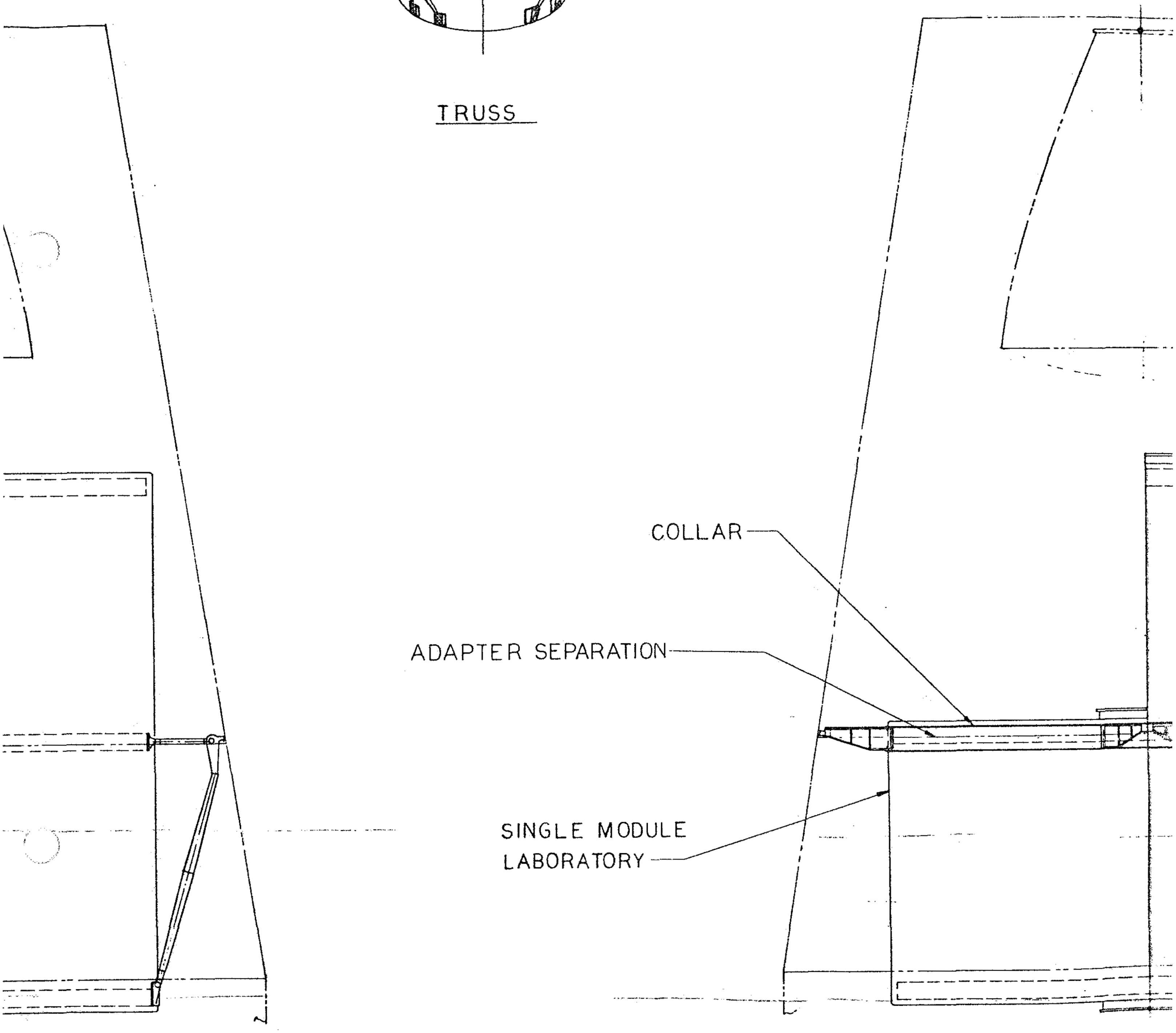
The launch configuration of a 260-in. diameter Operational Modular Multipurpose Space Station presents a hammerhead appearance. Parts of the shrouding would be retained as meteoroid shielding after the station is deployed in orbit. Further study and test are required to determine the launch characteristics of this arrangement. The launch configurations of the 260-in. diameter modular compartment stations are shown on Fig. 3-28.



TRUSS SUPPORT STF



TRUSS



RT STRUCTURE

BEAM SUP

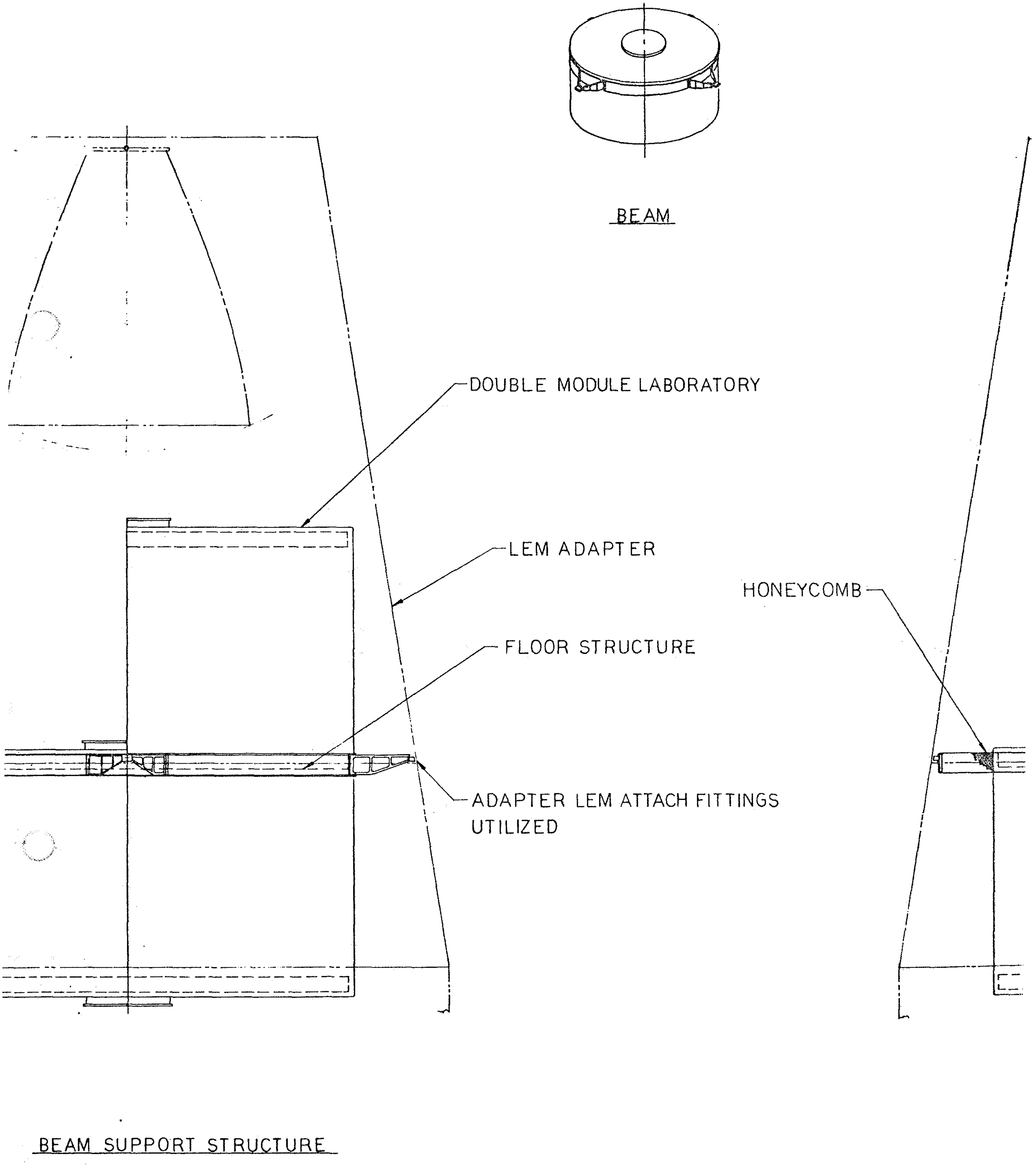
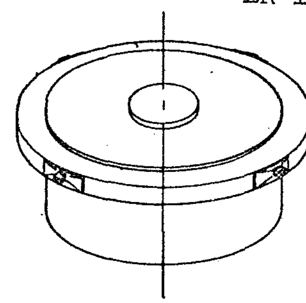
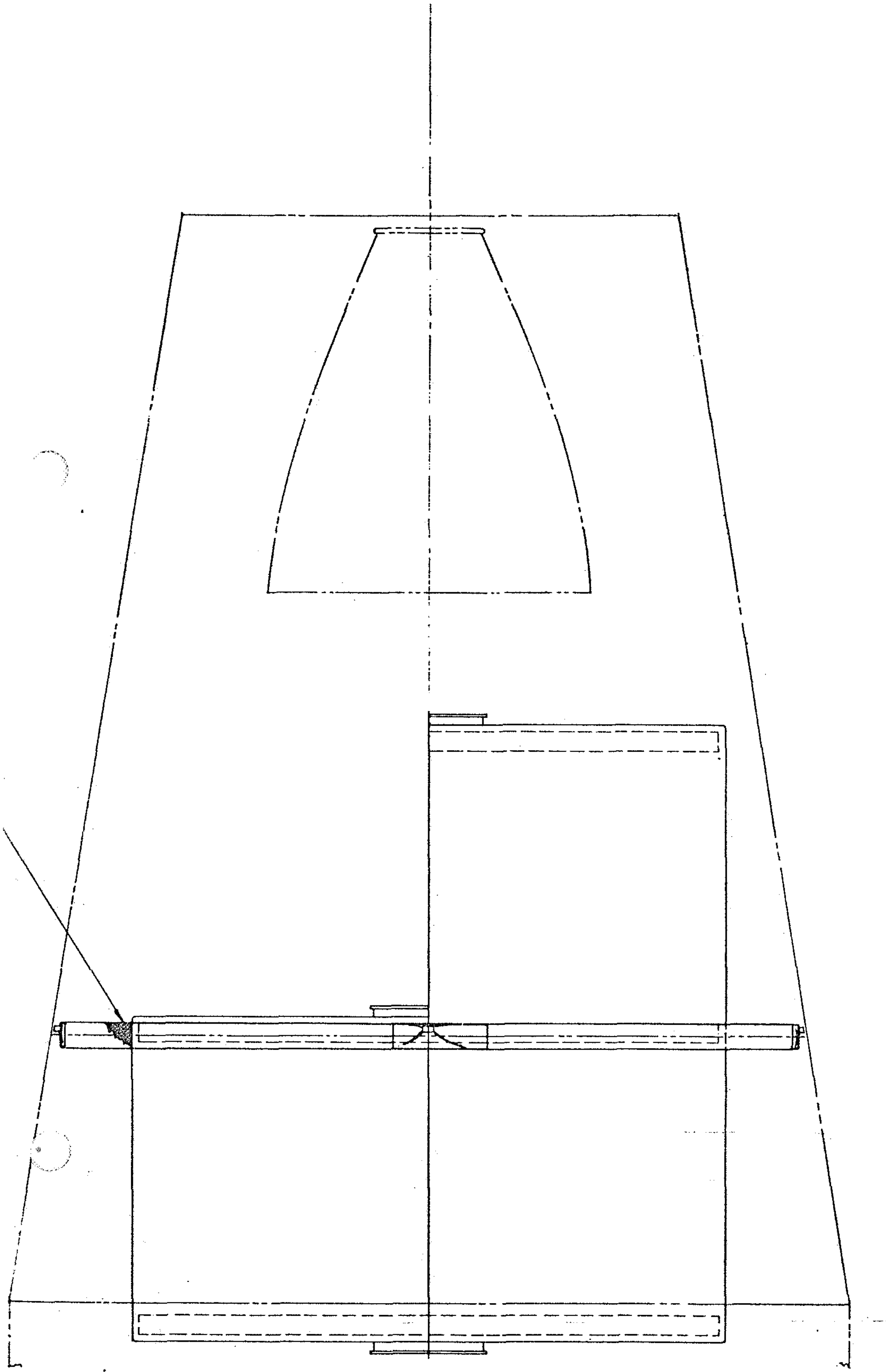

BEAM
DOUBLE MODULE LABORATORY
LEM ADAPTER
HONEYCOMB
FLOOR STRUCTURE
ADAPTER LEM ATTACH FITTINGS
UTILIZED
BEAM SUPPORT STRUCTURE

FIG. 3

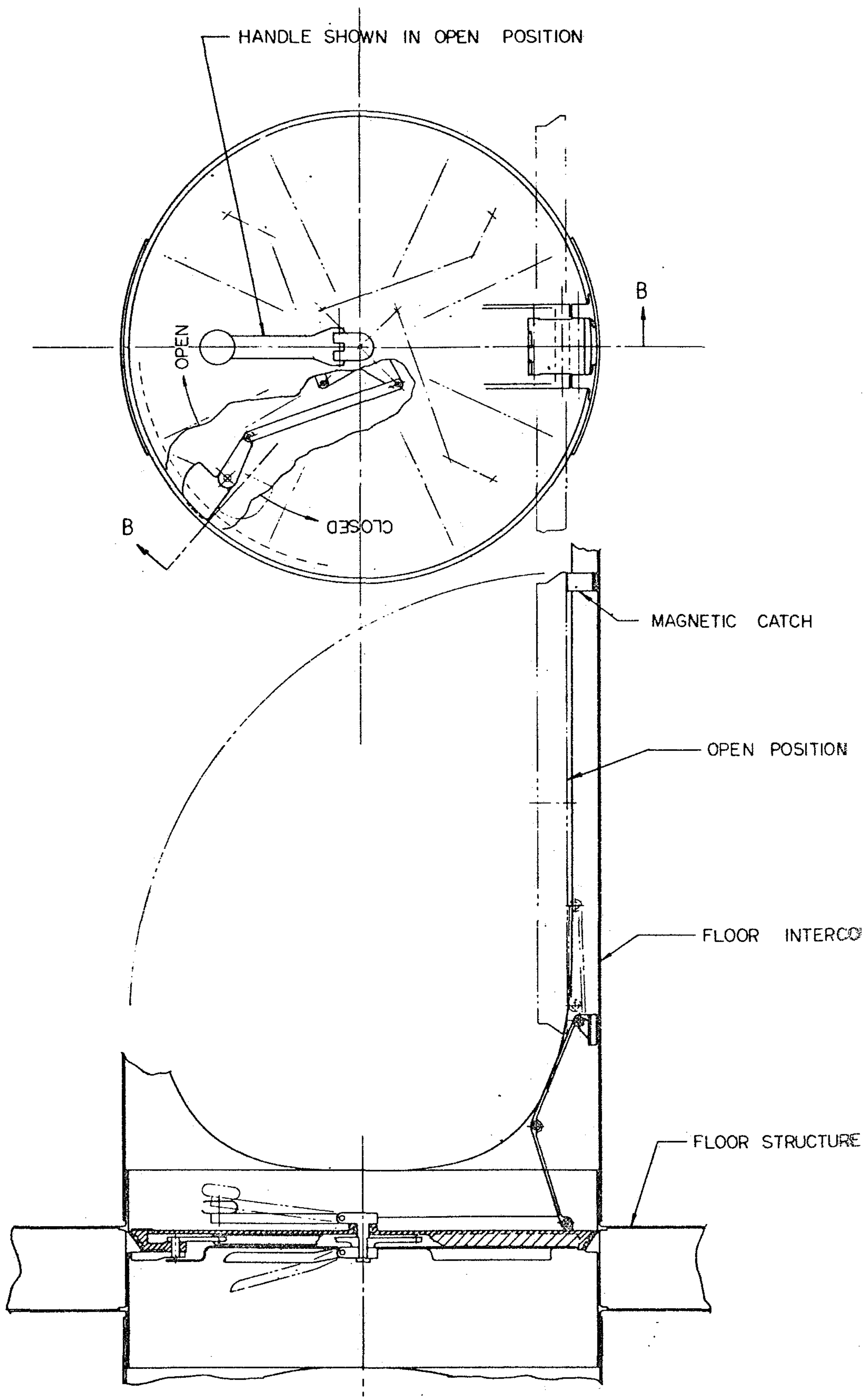


SHEAR

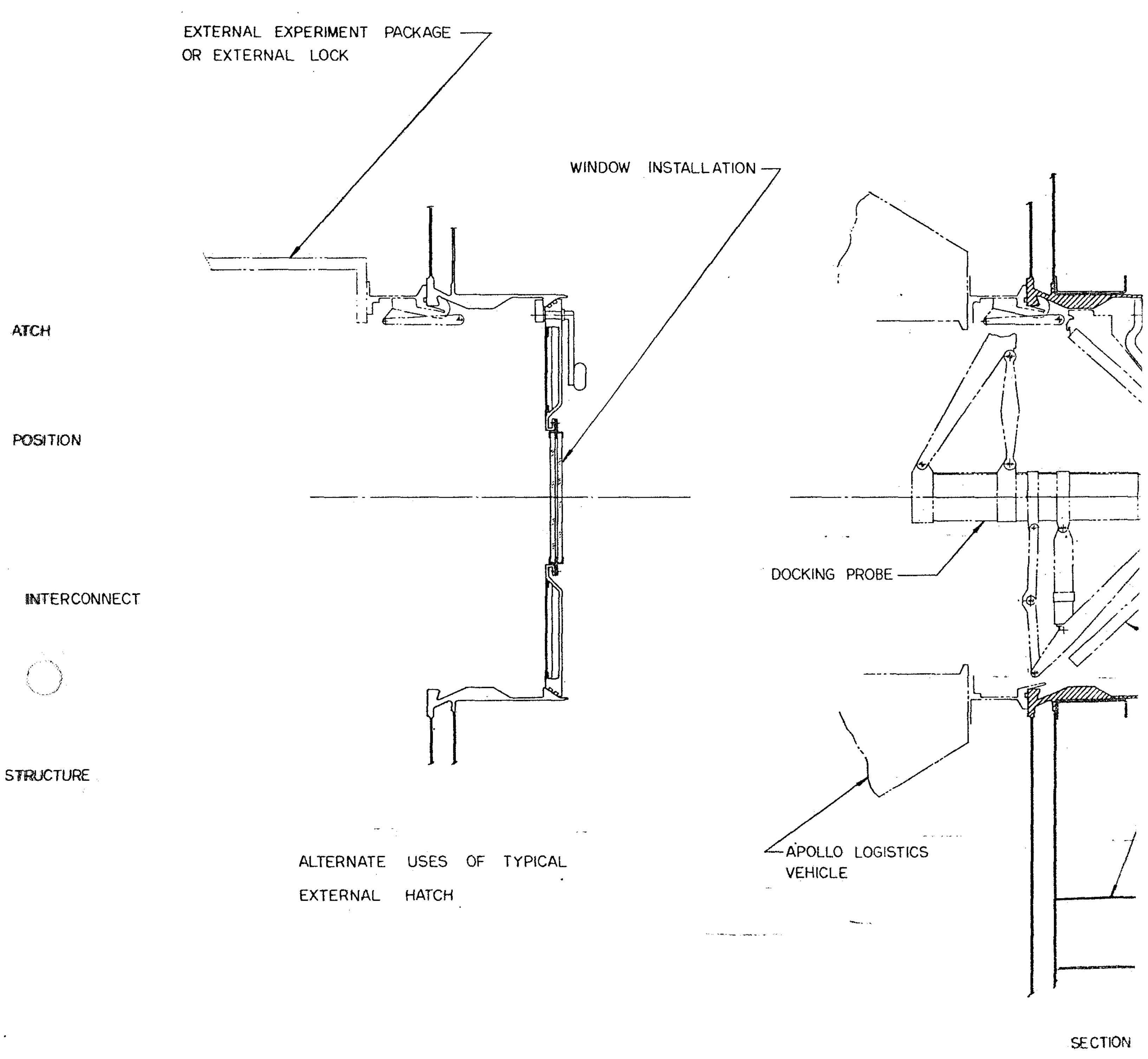


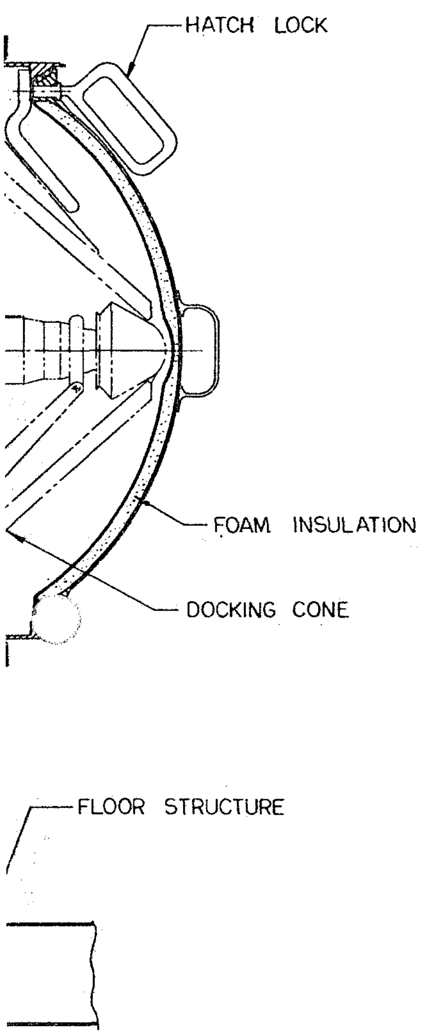
SHEAR RING STRUCTURE

FIG. 3-14 SUPPORT CONCEPTS, ONE- AND TWO-COMPARTMENT LABORATORIES

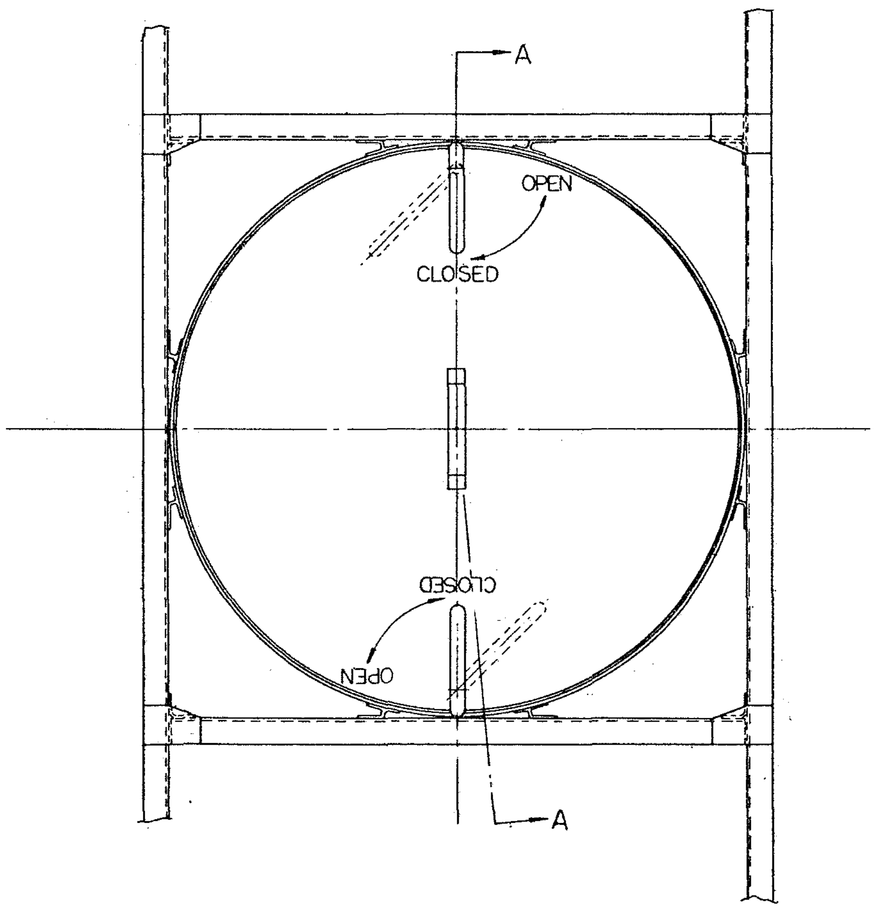


INTER-COMPARTMENT HATCH
SECTION B-B


EXTERNAL EXPERIMENT PACKAGE OR EXTERNAL LOCK
WINDOW INSTALLATION
ATCH
POSITION
INTERCONNECT
STRUCTURE
DOCKING PROBE
APOLLO LOGISTICS VEHICLE
ALTERNATE USES OF TYPICAL EXTERNAL HATCH
SECTION



TYPICAL HATCH IN SIDES & ENDS
OF MODULE
N A-A



TYPICAL H

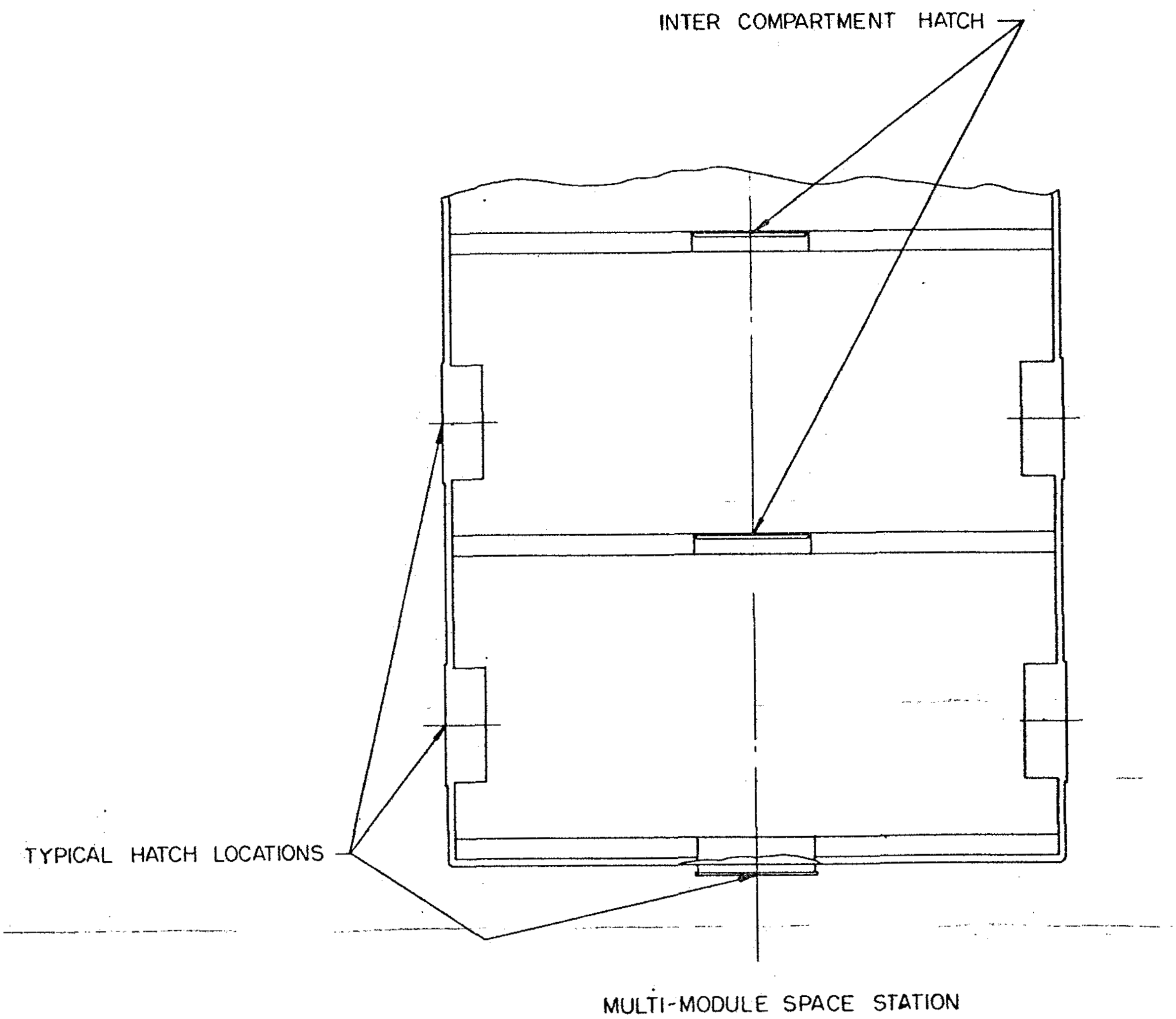
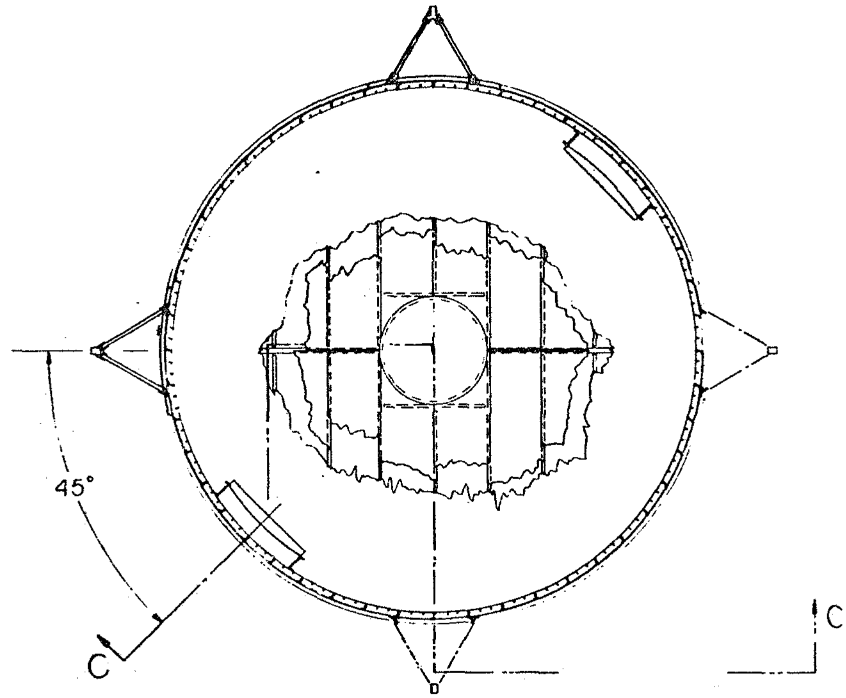
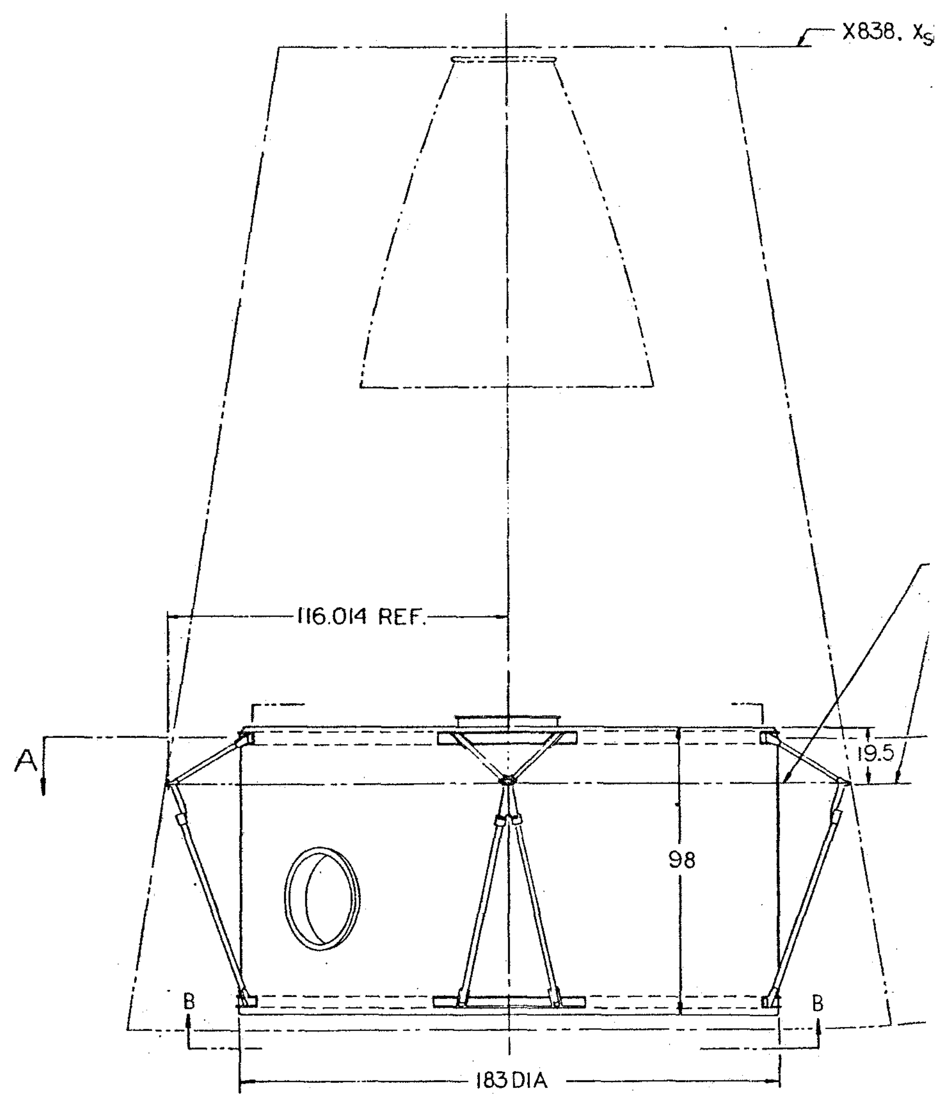


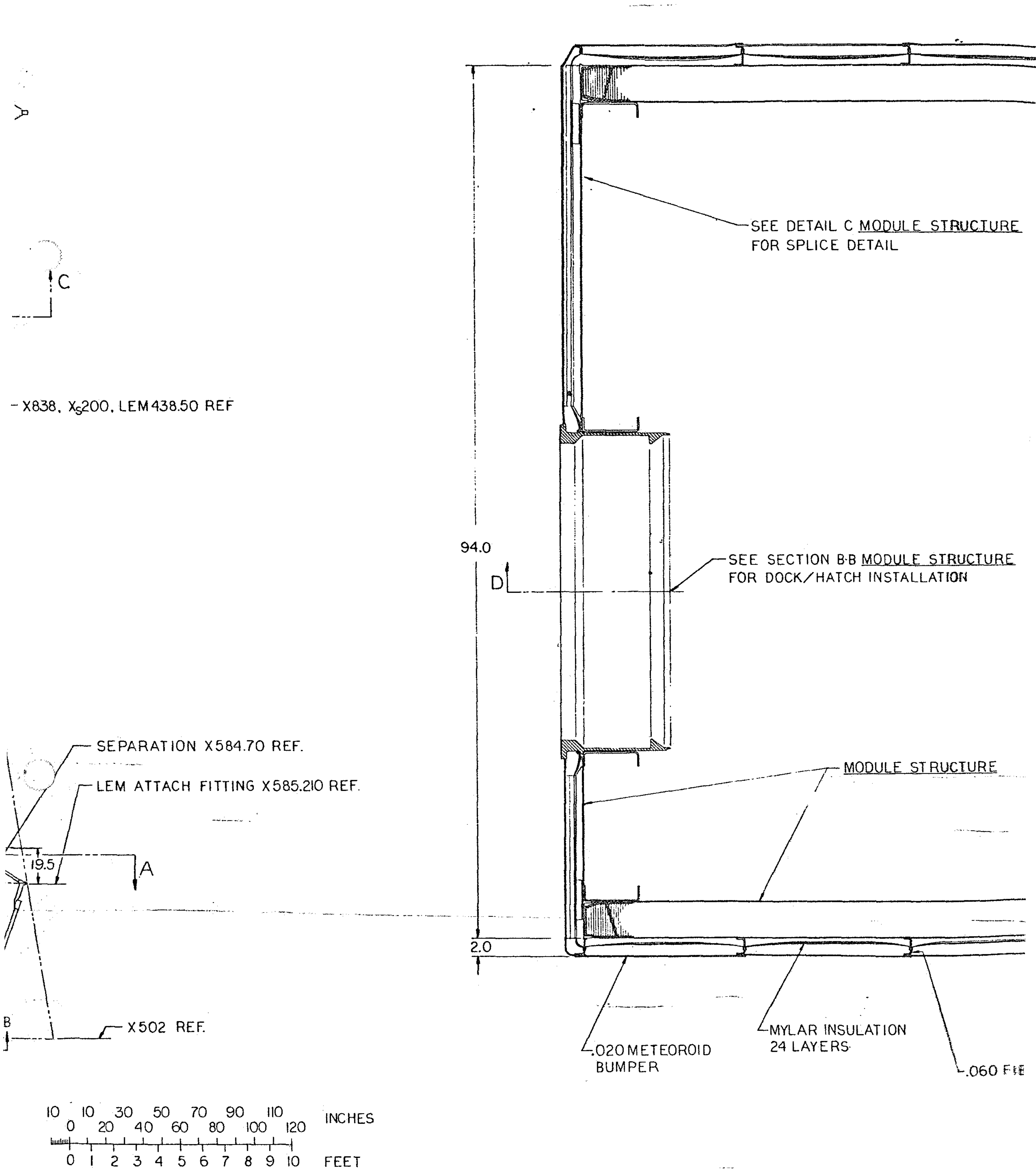
FIG. 3-15 UNIVERSAL HATCH, TYPICAL APPLICATION



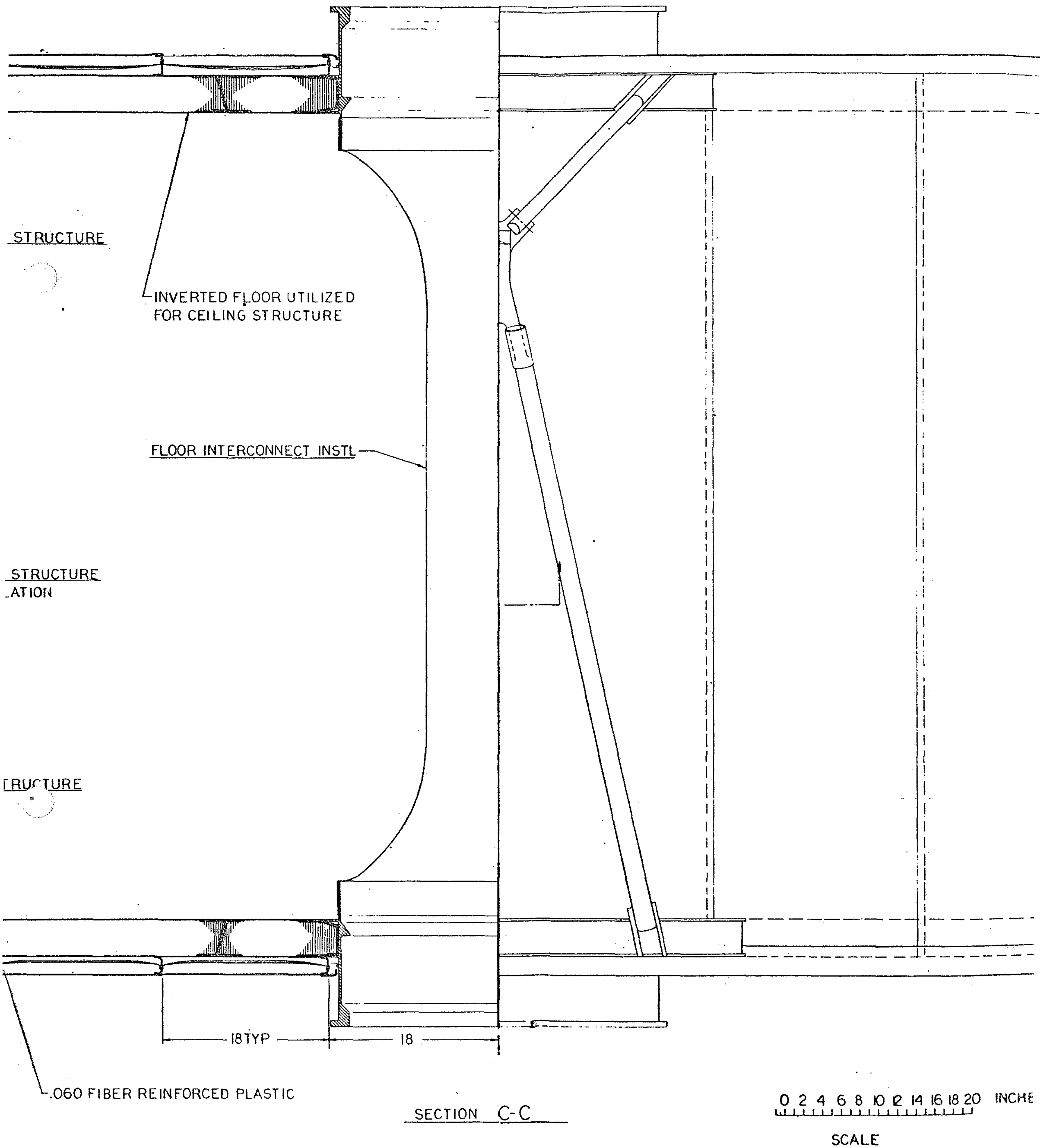
SECTION A-A



INSTALLATION IN STANDARD LEM ADAPTER



C
X838, X_S200, LEM 438.50 REF
SEE DETAIL C MODULE STRUCTURE
FOR SPLICE DETAIL
94.0
D
SEE SECTION B-B MODULE STRUCTURE
FOR DOCK/HATCH INSTALLATION
SEPARATION X584.70 REF.
LEM ATTACH FITTING X585.210 REF.
MODULE STRUCTURE
19.5
A
2.0
B
X502 REF.
.020 METEOROID
BUMPER
MYLAR INSULATION
24 LAYERS
.060 FIE
10 10 30 50 70 90 110
0 20 40 60 80 100 120
INCHES
0 1 2 3 4 5 6 7 8 9 10
FEET



SECTION C-C

FIG.

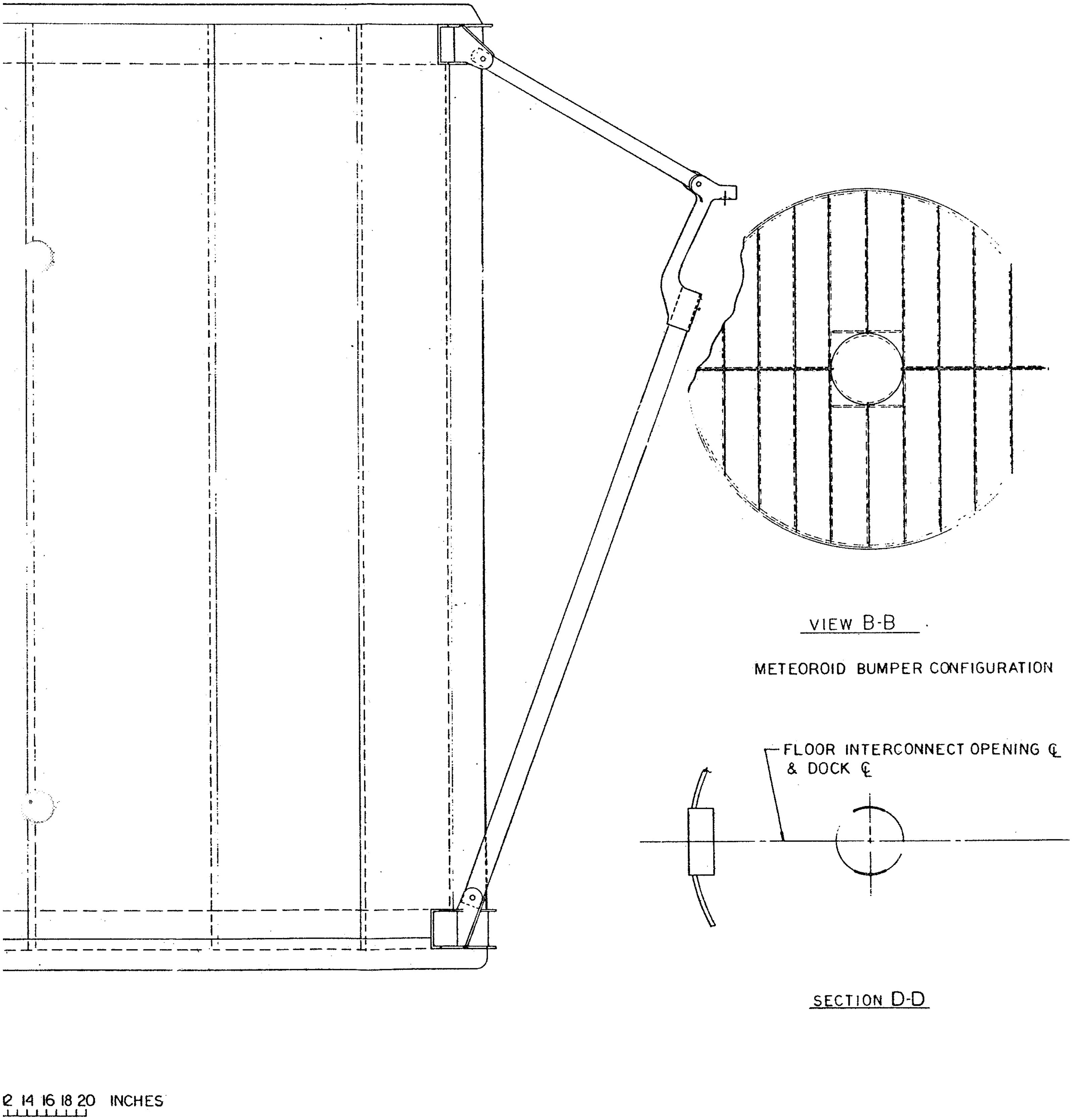
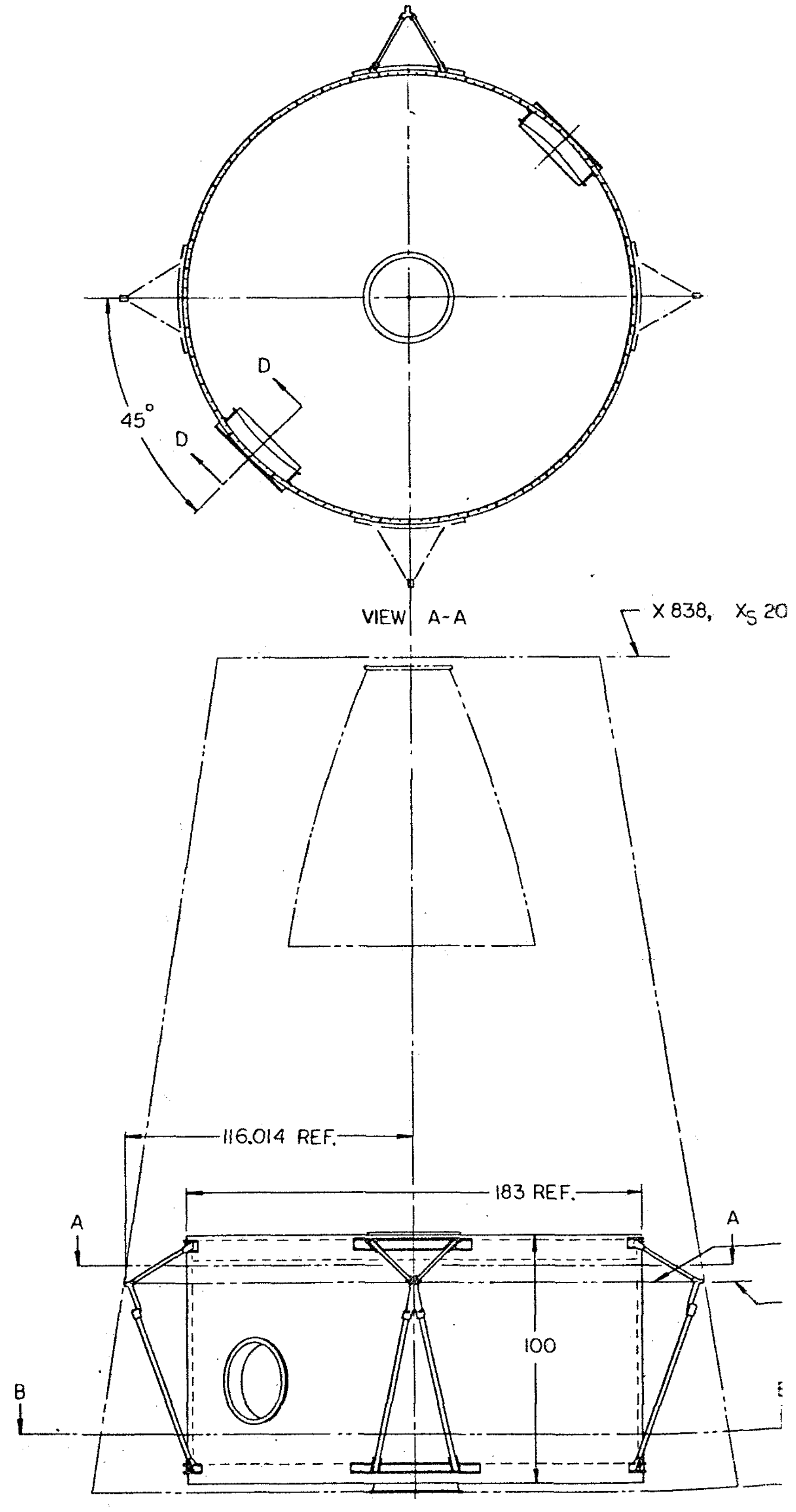


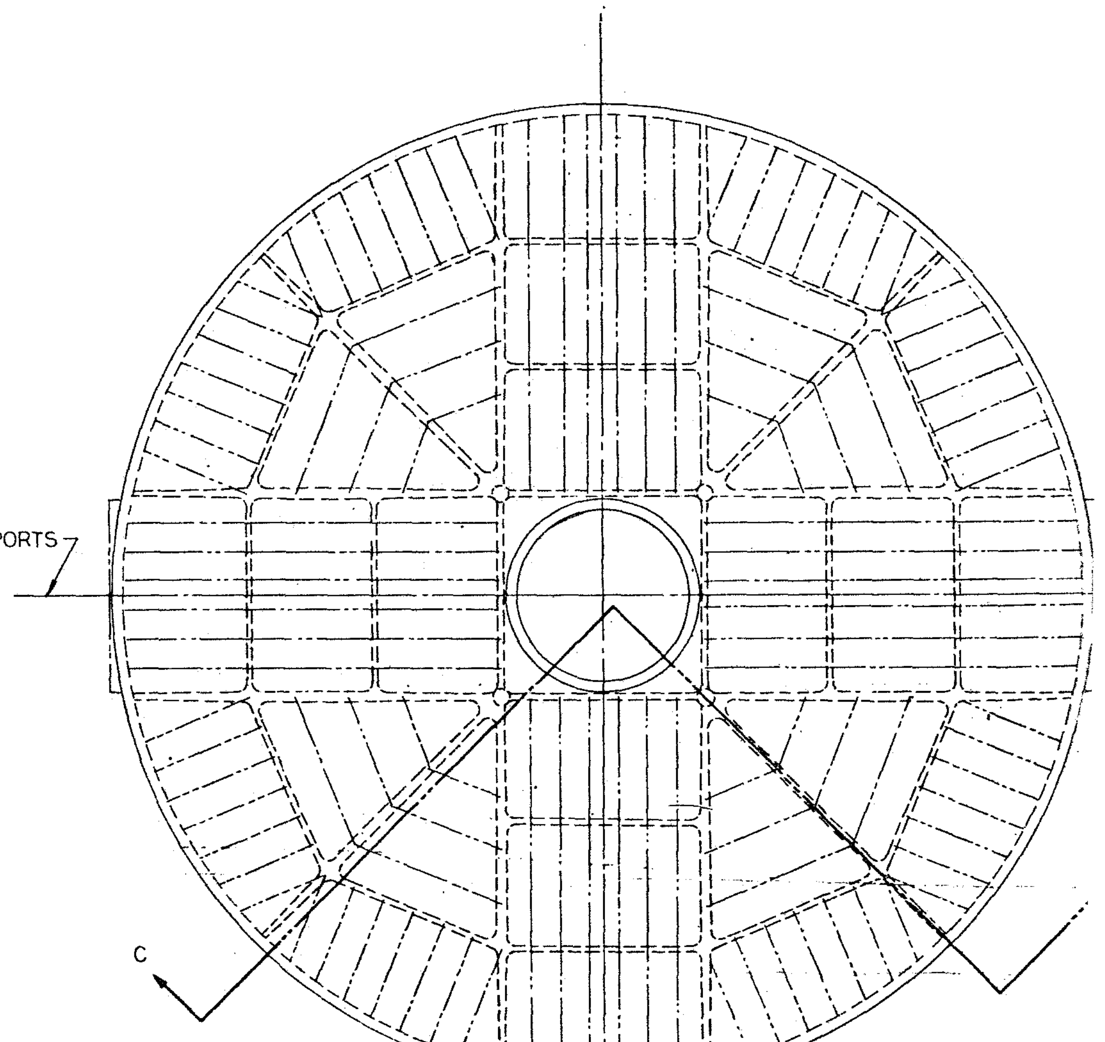
FIG. 3-16 ONE-COMPARTMENT LABORATORY ASSEMBLY, HONEYCOMB FLOOR



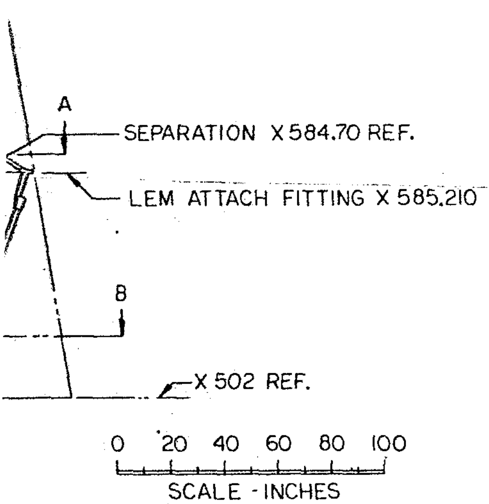
INSTALLATION IN STANDARD LEM ADAPTER

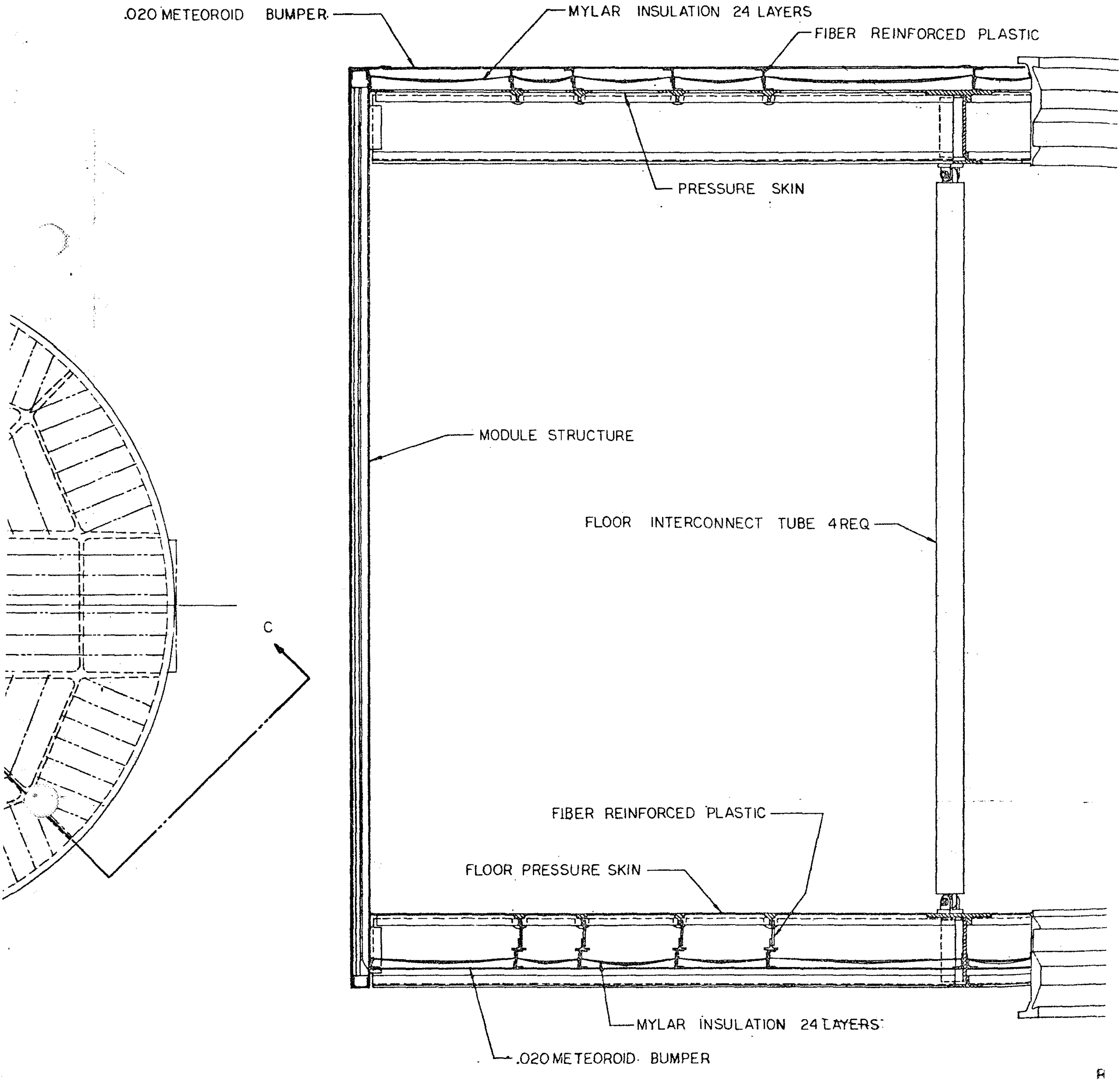
.020 ME

38, X_S 200,LEM 438.50 REF.



VIEW B - B
ROTATED 45° CLOCKWISE




.020 METEOROID BUMPER
MYLAR INSULATION 24 LAYERS
FIBER REINFORCED PLASTIC
PRESSURE SKIN
MODULE STRUCTURE
FLOOR INTERCONNECT TUBE 4 REQ
C
FIBER REINFORCED PLASTIC
FLOOR PRESSURE SKIN
MYLAR INSULATION 24 LAYERS
.020 METEOROID BUMPER
R

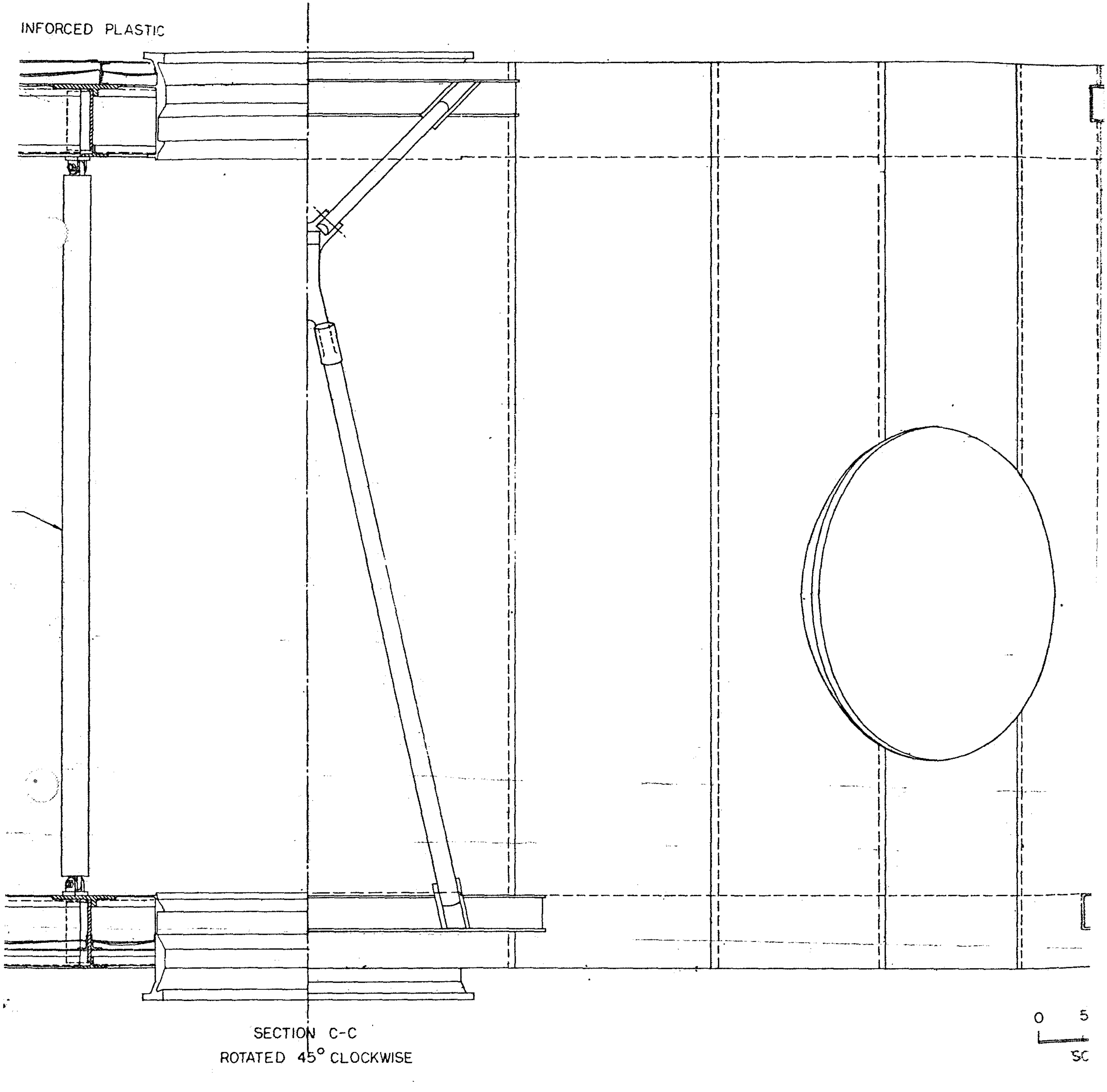


FIG. 3-

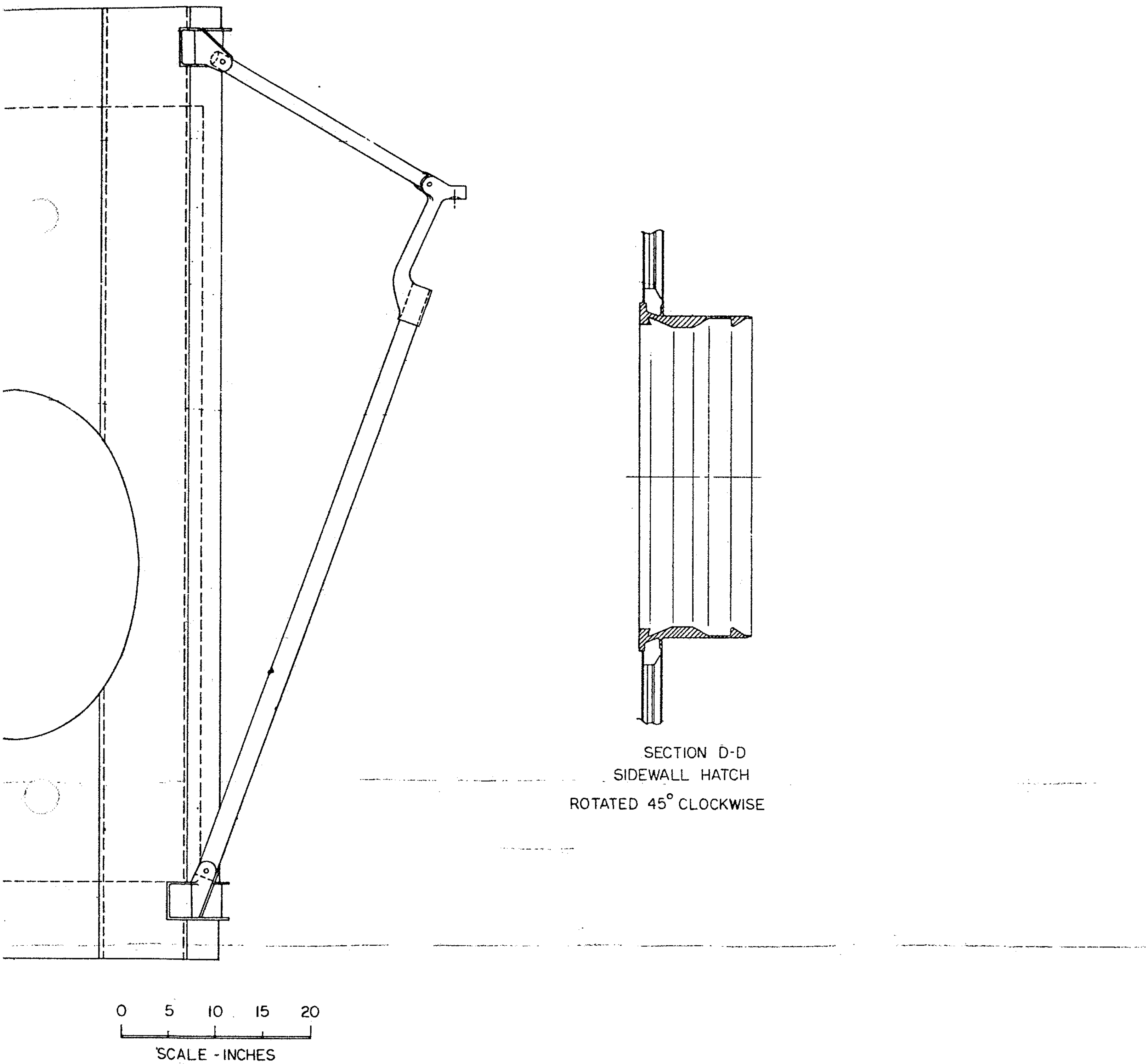
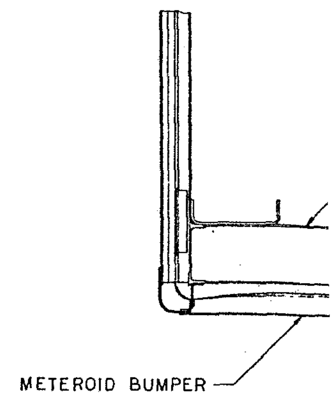
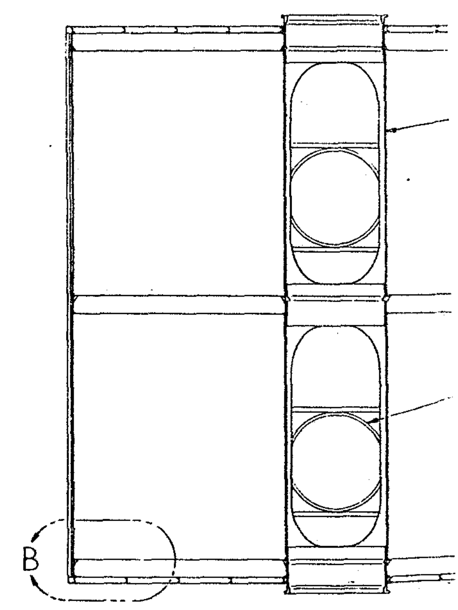


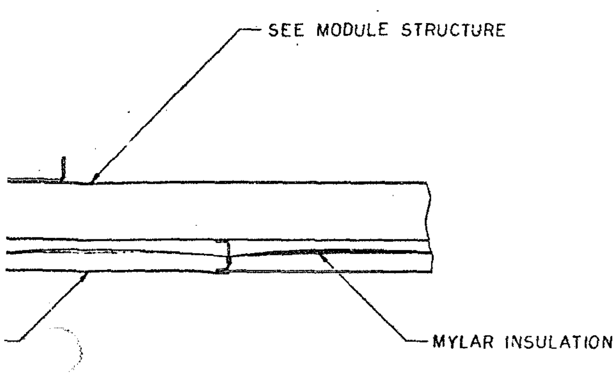
FIG. 3-17 ONE COMPARTMENT LABORATORY ASSEMBLY, BEAM FLOOR



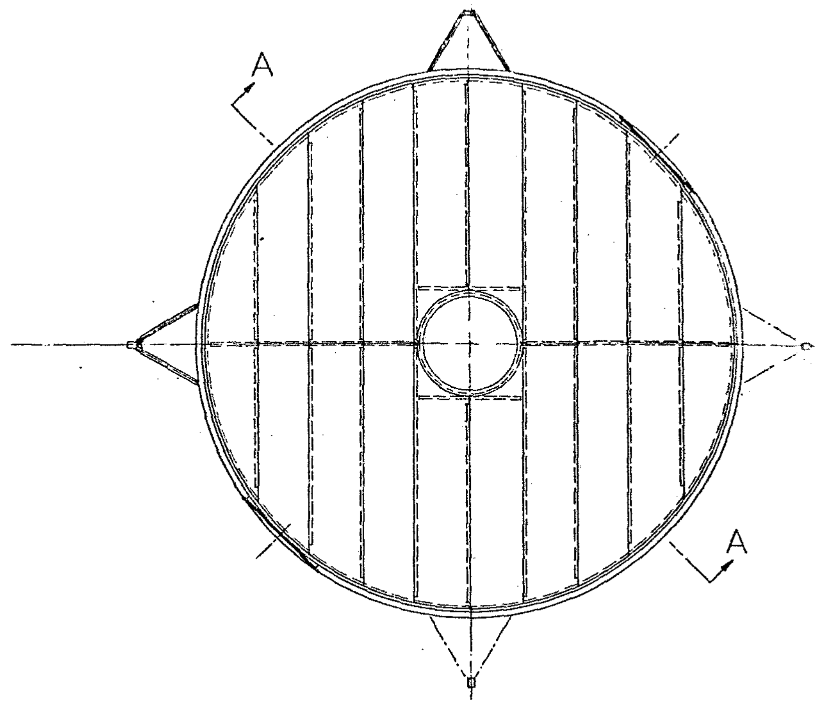
DE

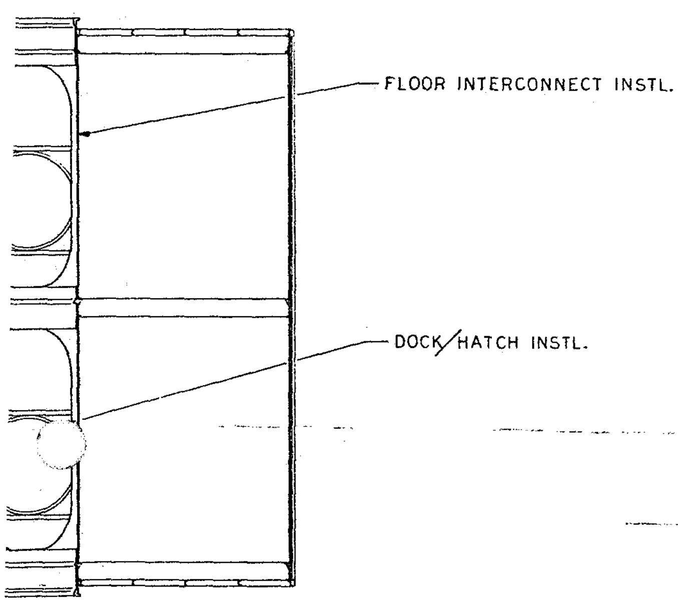


SECTION A - A

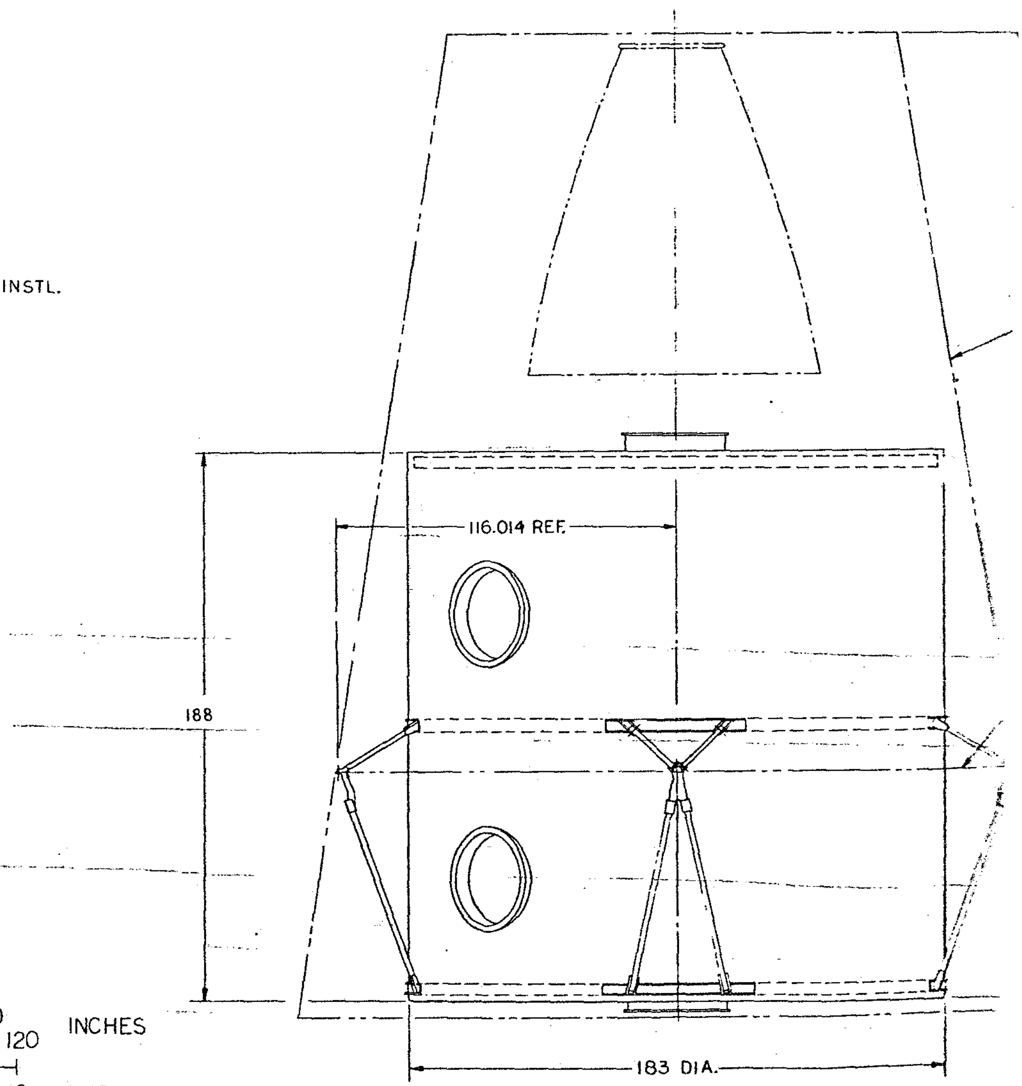


DETAIL - B





N A-A



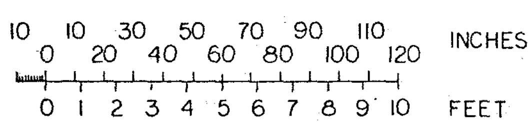


FIG. 3-18 TWO CC

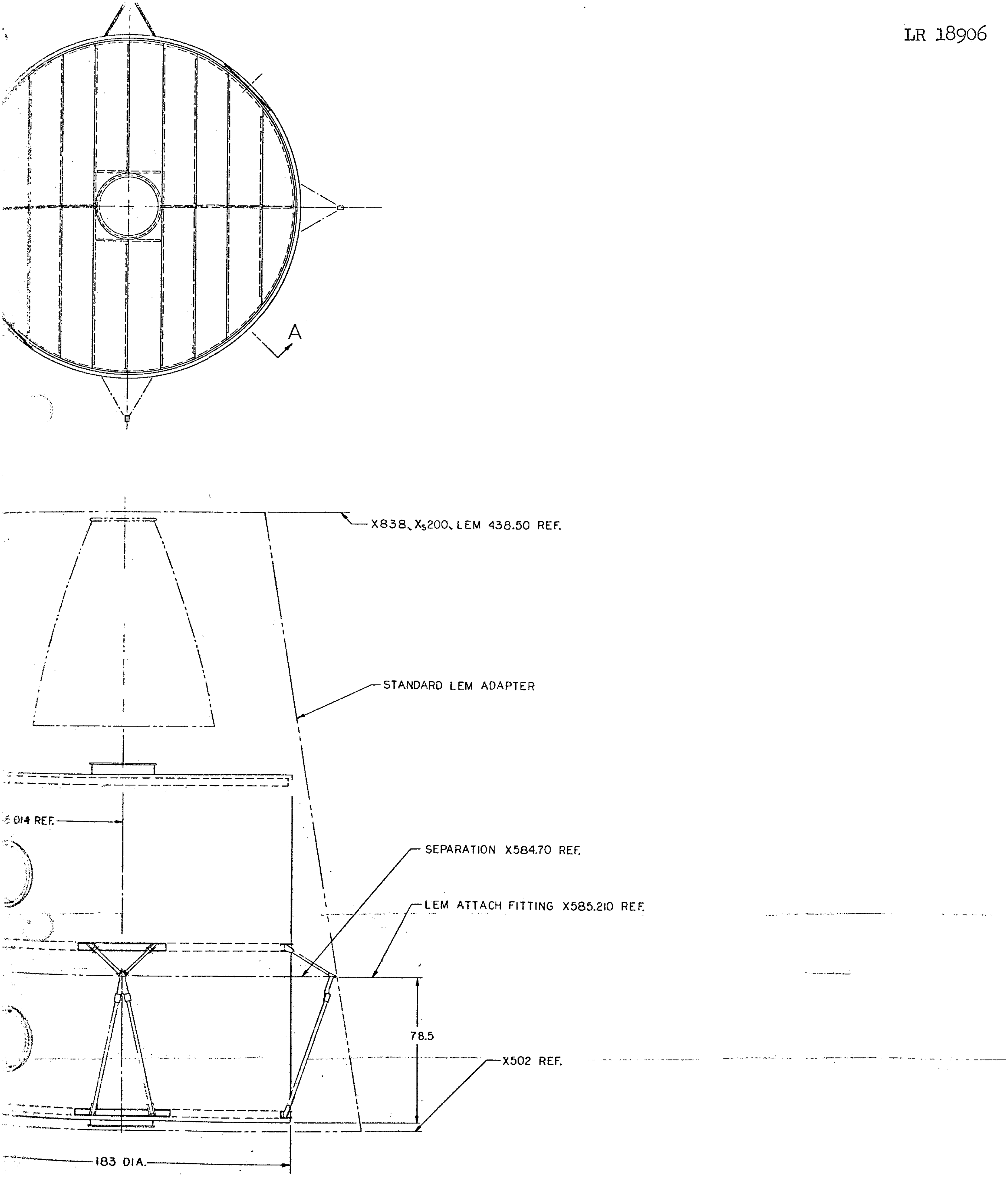
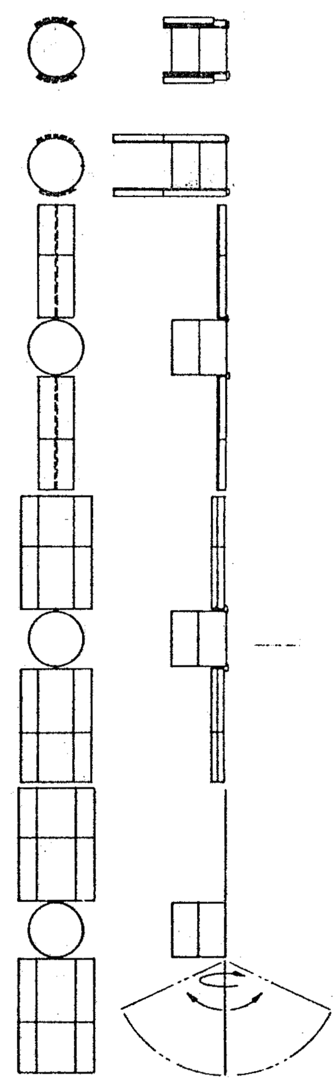
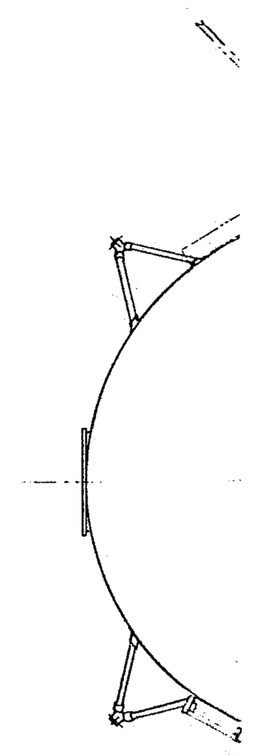
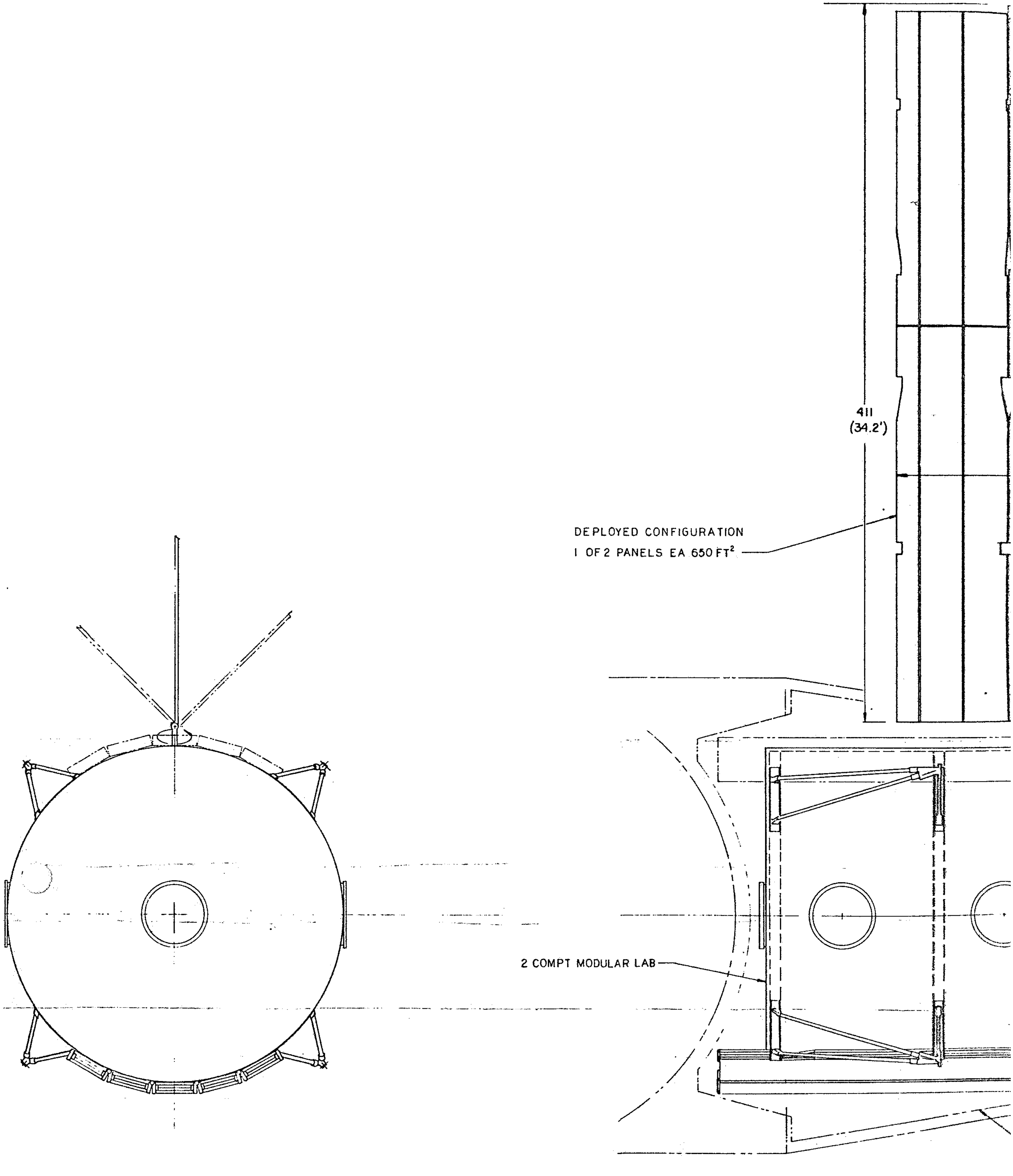


FIG. 3-18 TWO COMPARTMENT LABORATORY ASSEMBLY

SCHEMATIC - SOLAR
ARRAY DEPLOYMENT







411
(34.2')
DEPLOYED CONFIGURATION
1 OF 2 PANELS EA 650 FT²
2 COMPT MODULAR LAB

LR

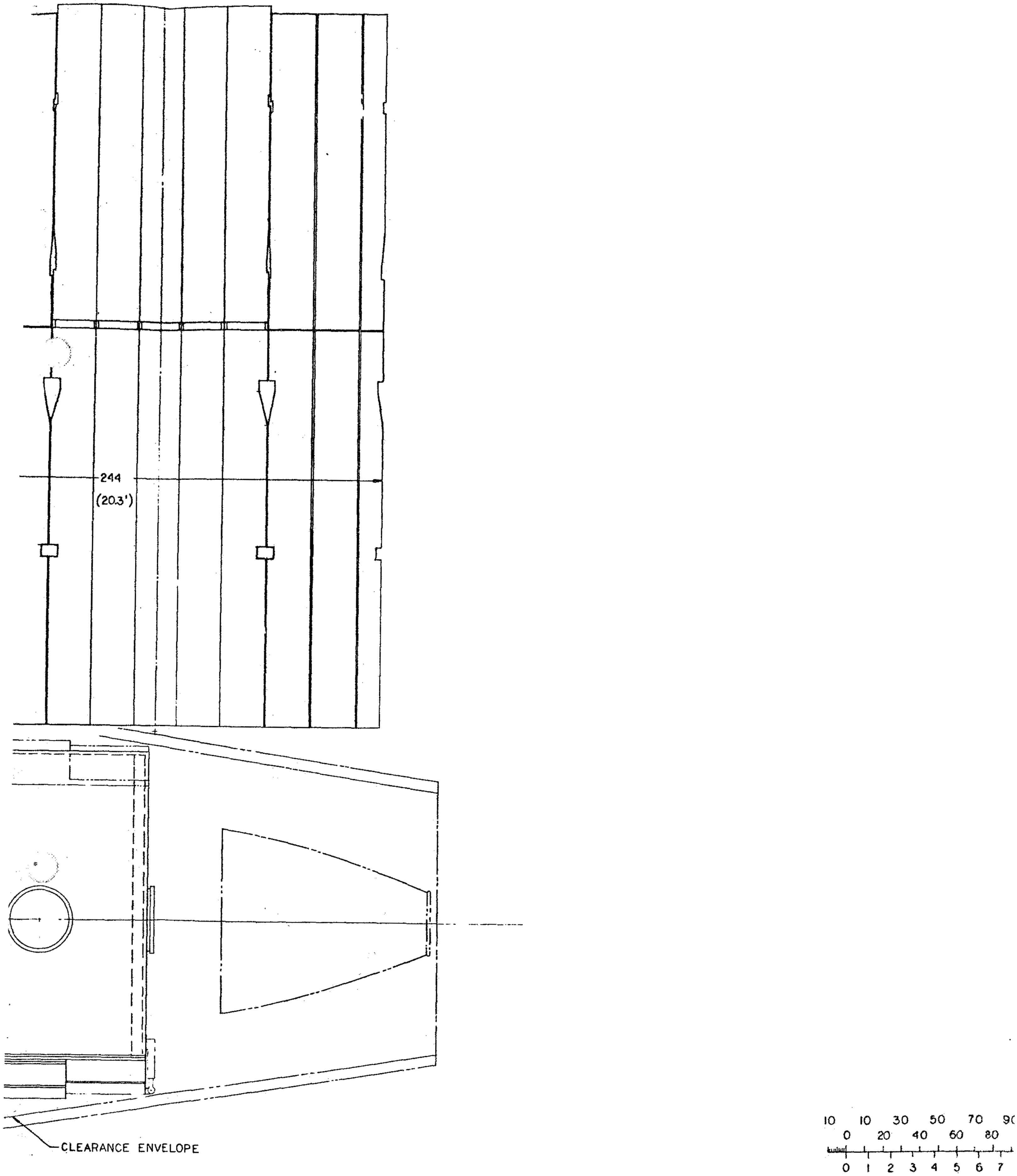


FIG. 3-19 RECTANGULAR SOLAR ARRAY- TWO COMPARTMENT LABOR

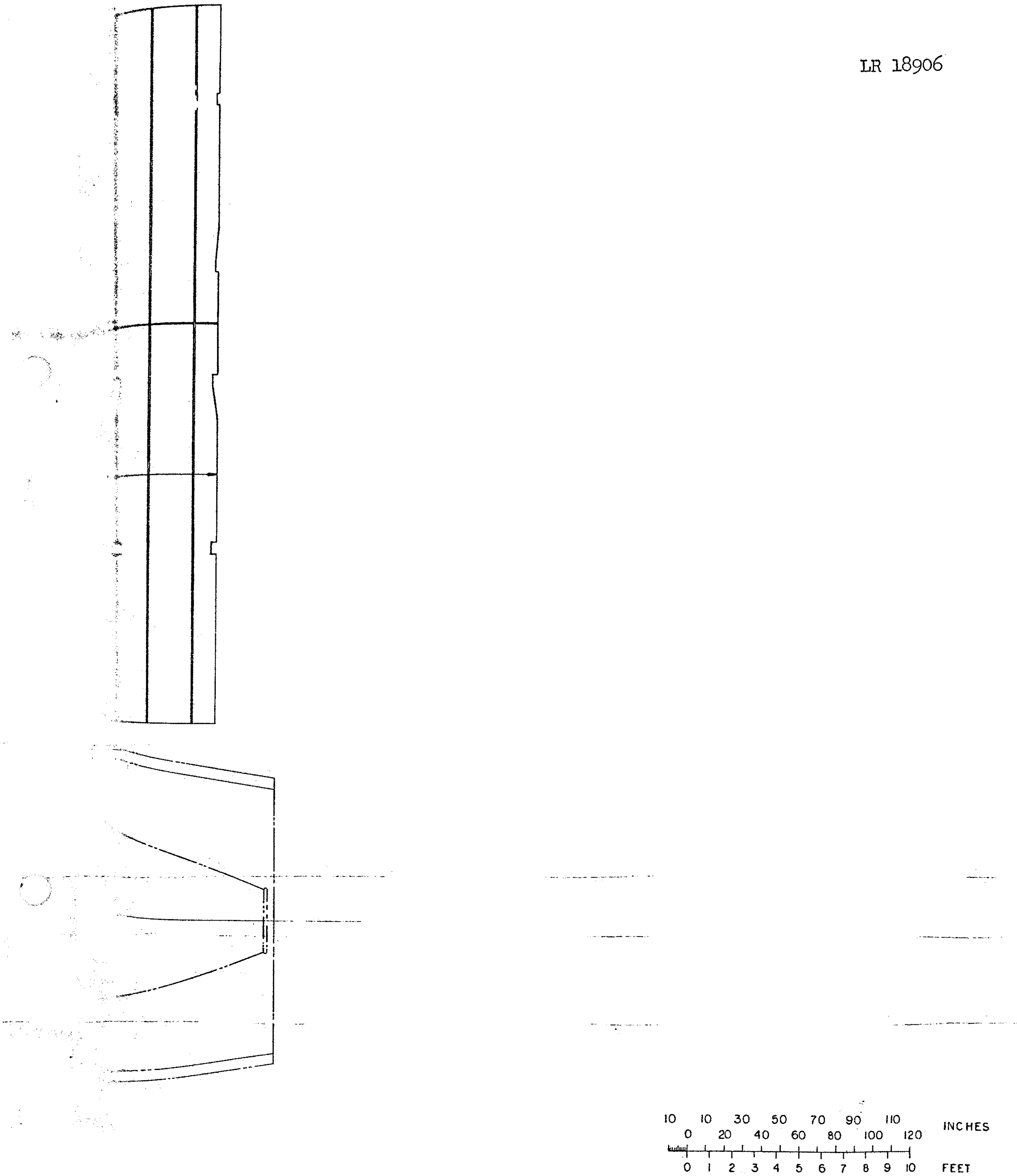
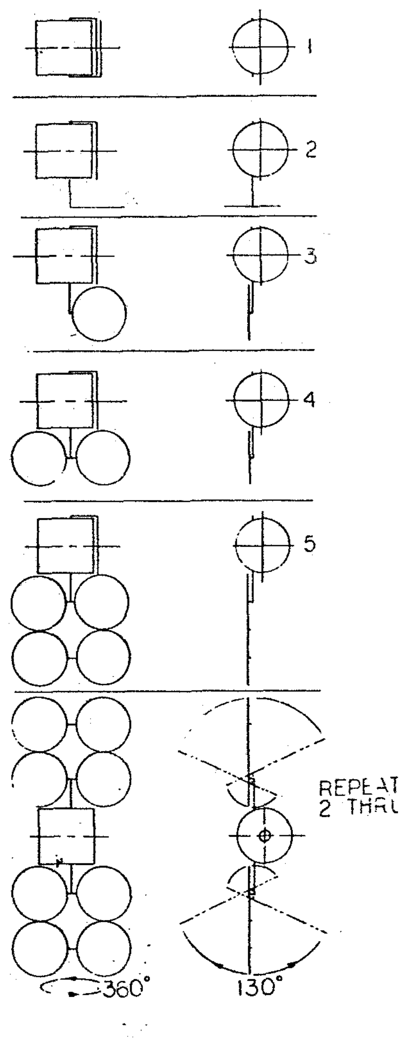


FIG. 3-19 RECTANGULAR SOLAR ARRAY- TWO COMPARTMENT LABORATORIES

SCHEMATIC-
SOLAR ARRAY
DEPLOYMENT



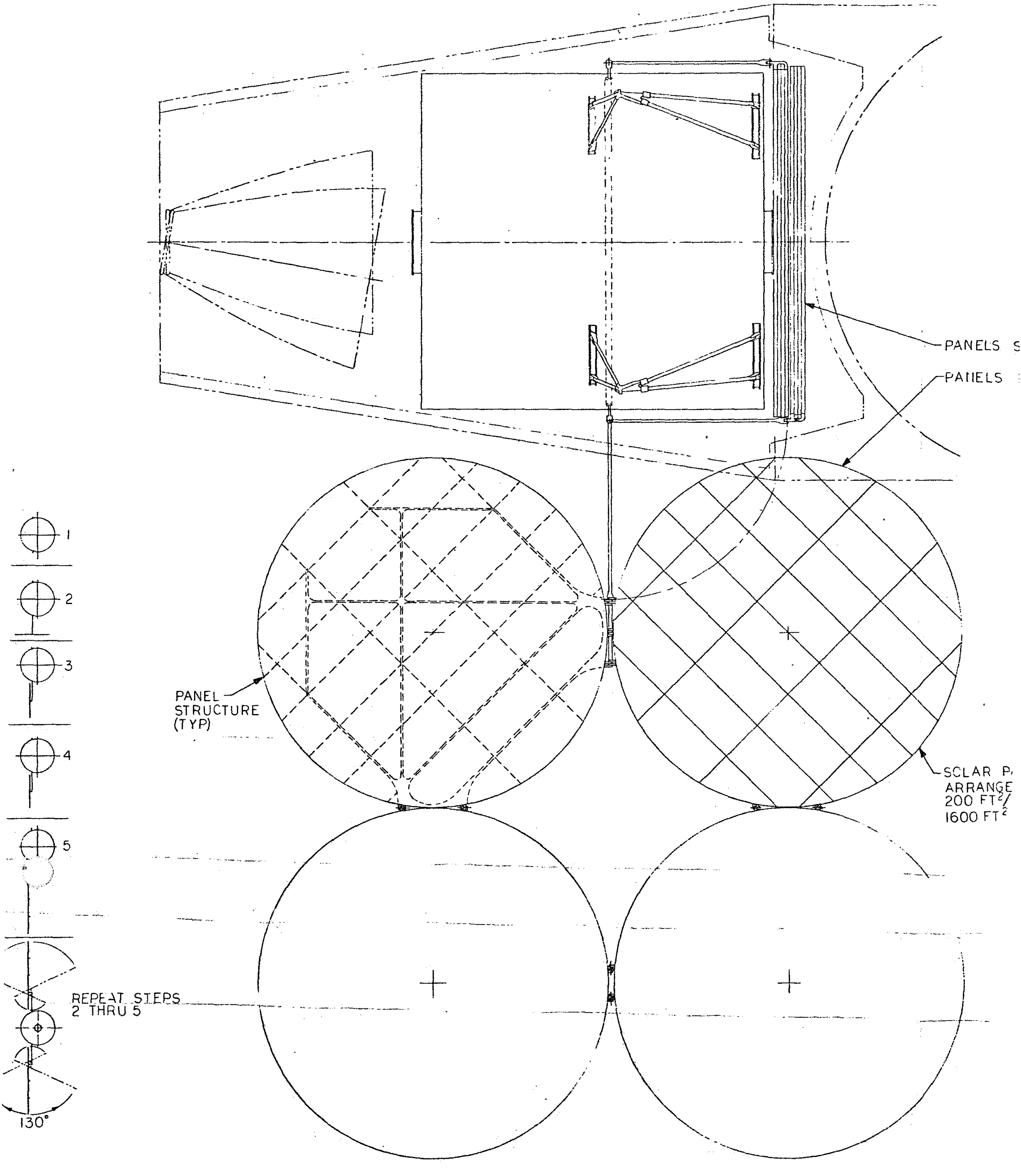

PANELS S
PANELS
PANEL STRUCTURE (TYP)
SOLAR P
ARRANGE
200 FT²/
1600 FT²
1
2
3
4
5
REPEAT STEPS 2 THRU 5
130°

FIG. 3-20 C

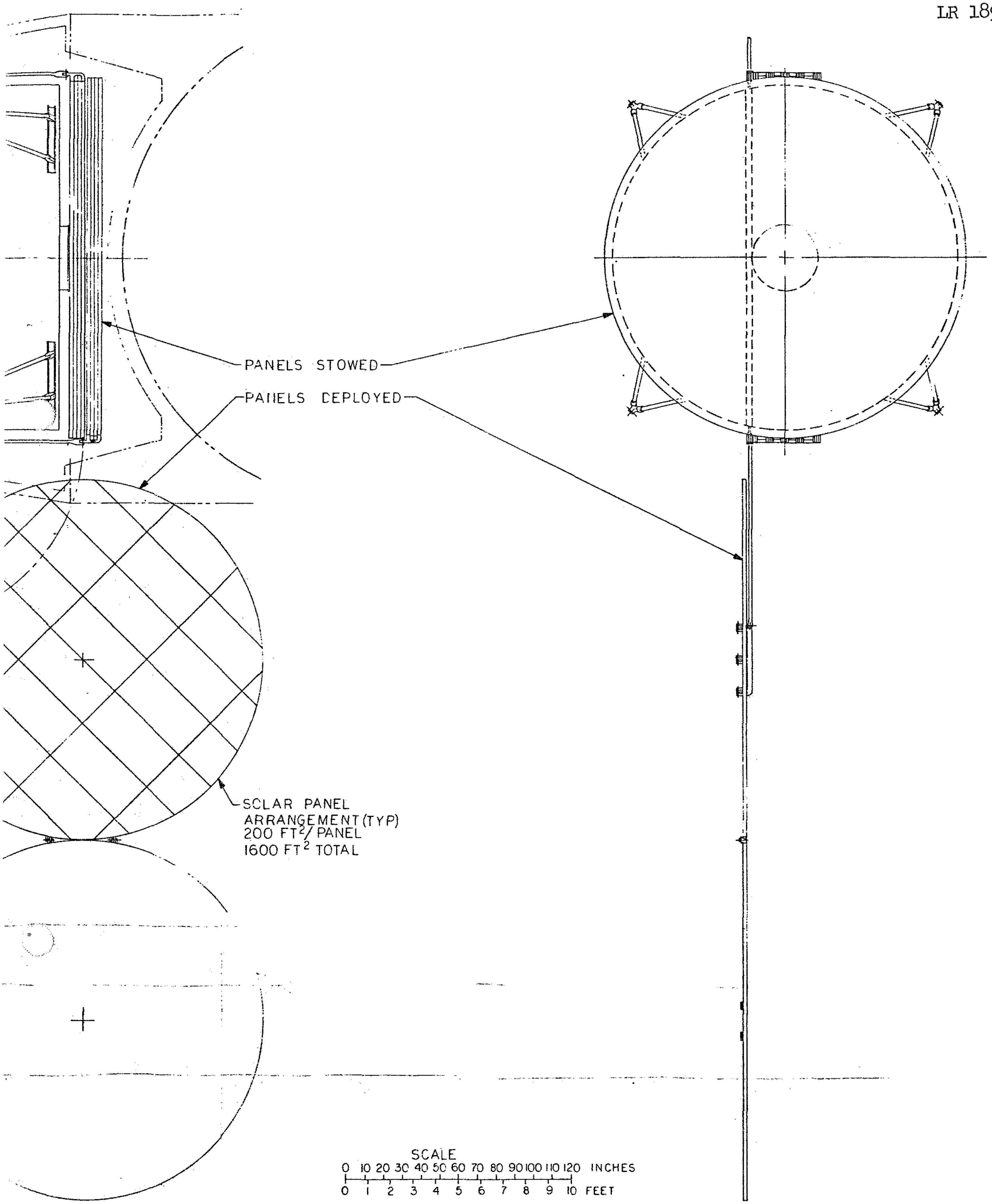
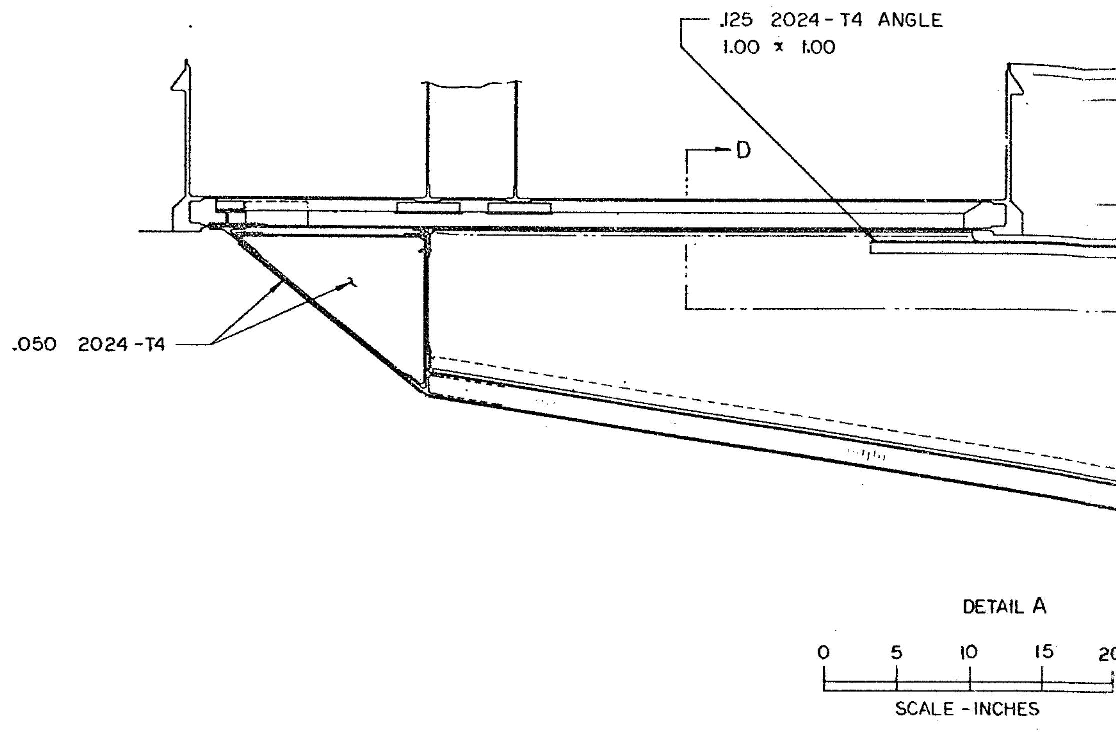
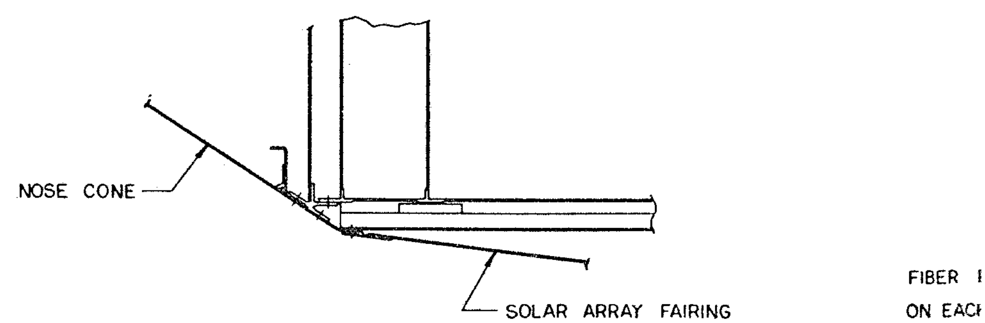


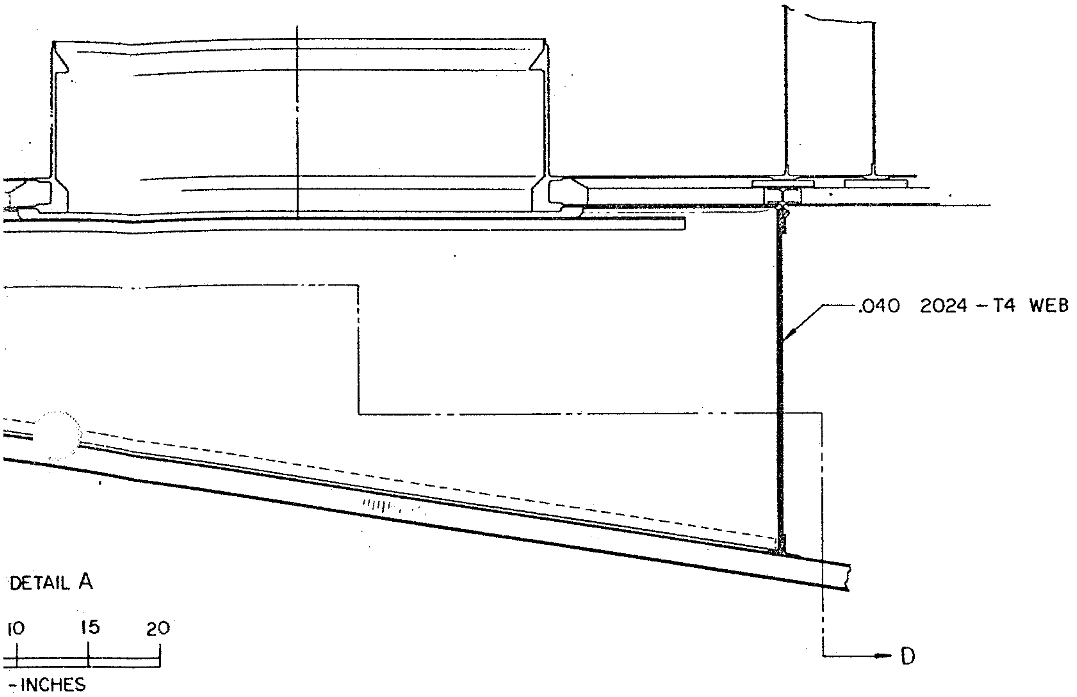
FIG. 3-20 CIRCULAR SOLAR ARRAY - TWO COMPARTMENT LABORATORIES



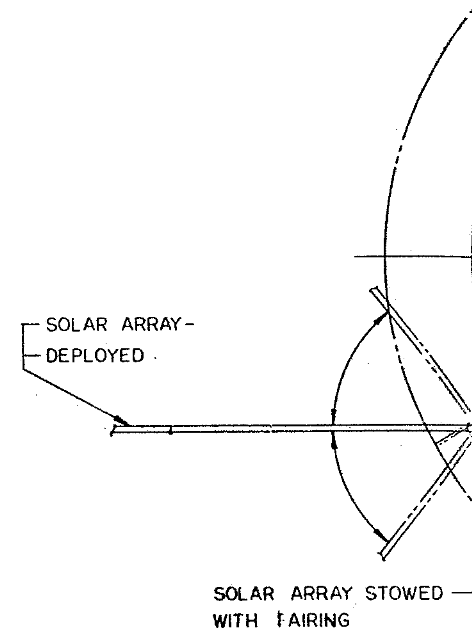
DETAIL A

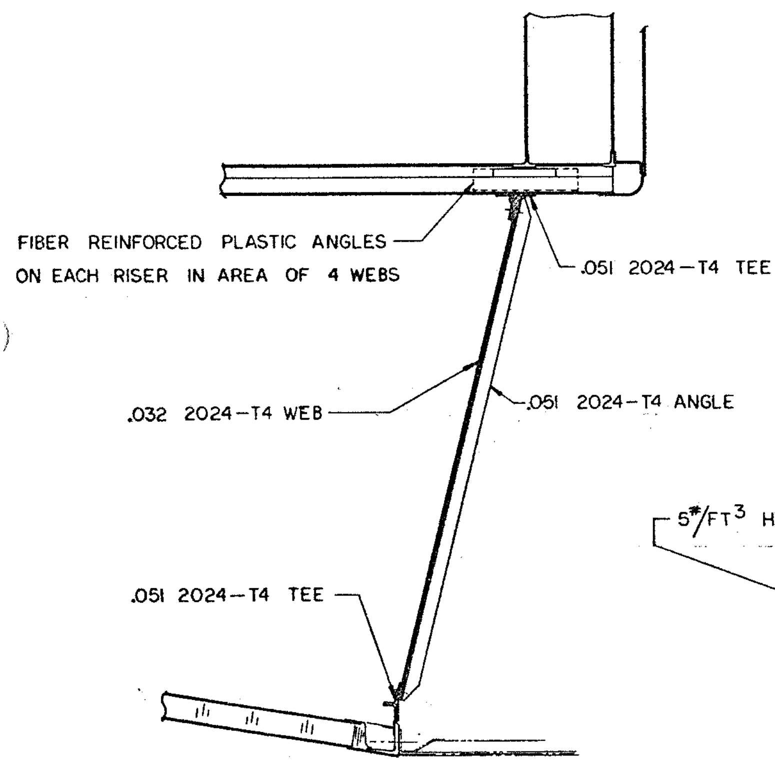


DETAIL C

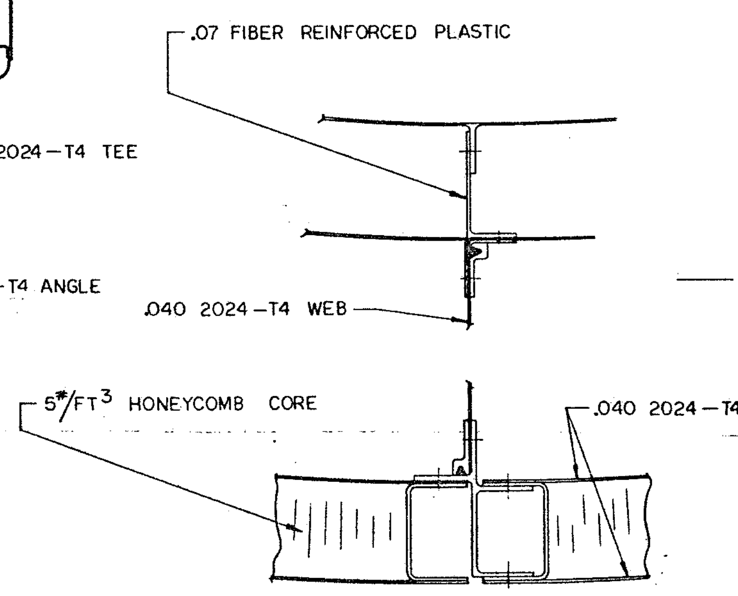


DETAIL A



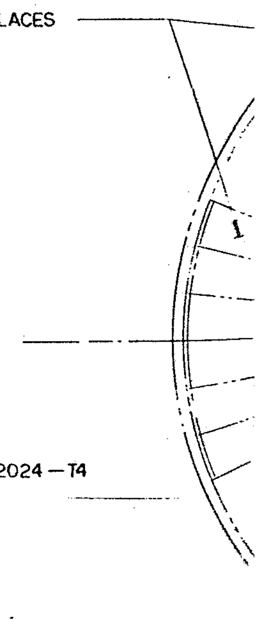


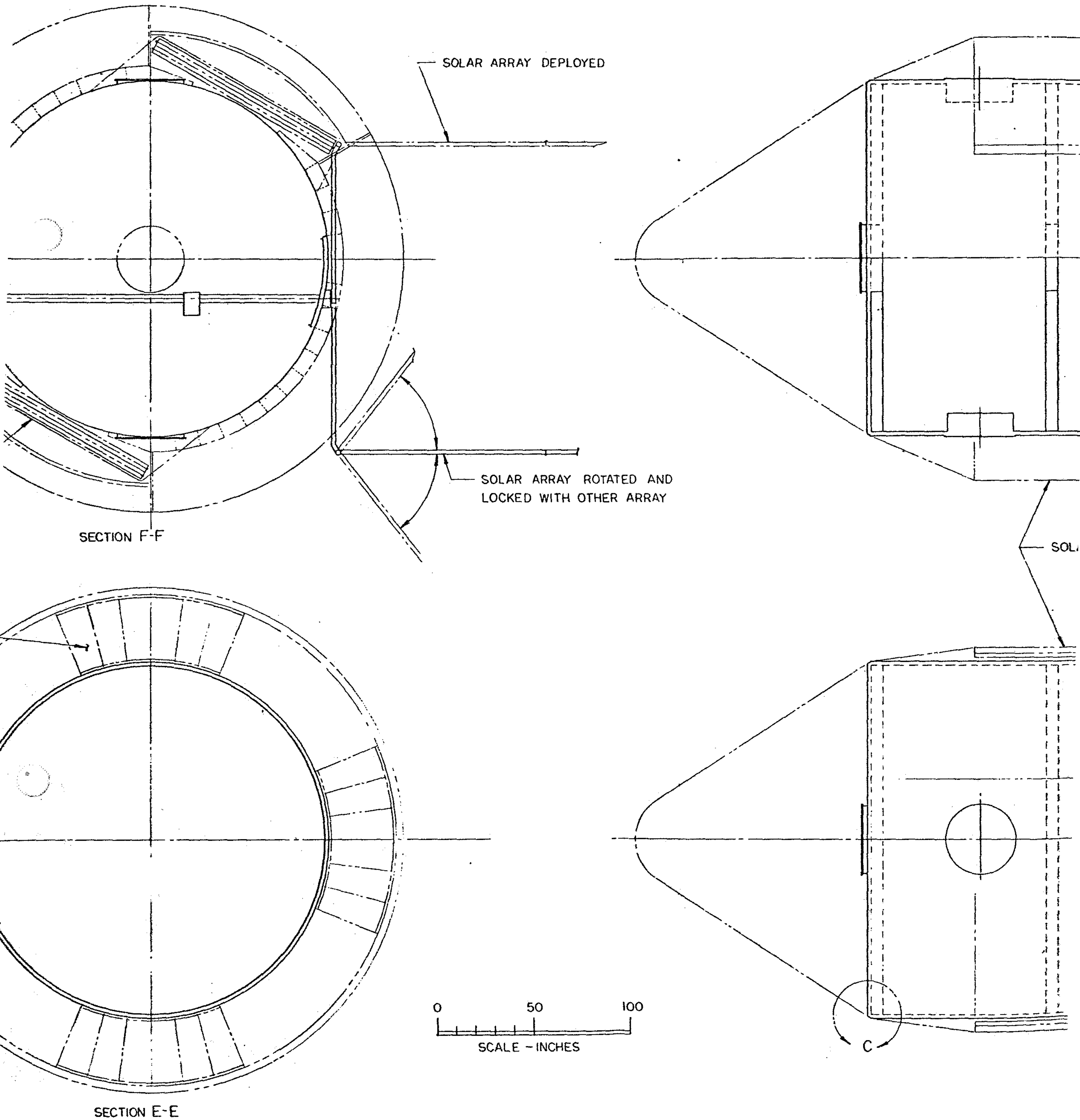
DETAIL B



SECTION D-D

0 1 2 3
SCALE - INCHES




SOLAR ARRAY DEPLOYED
SOLAR ARRAY ROTATED AND
LOCKED WITH OTHER ARRAY
SECTION F-F
SECTION E-E
0
50
100
SCALE - INCHES
C

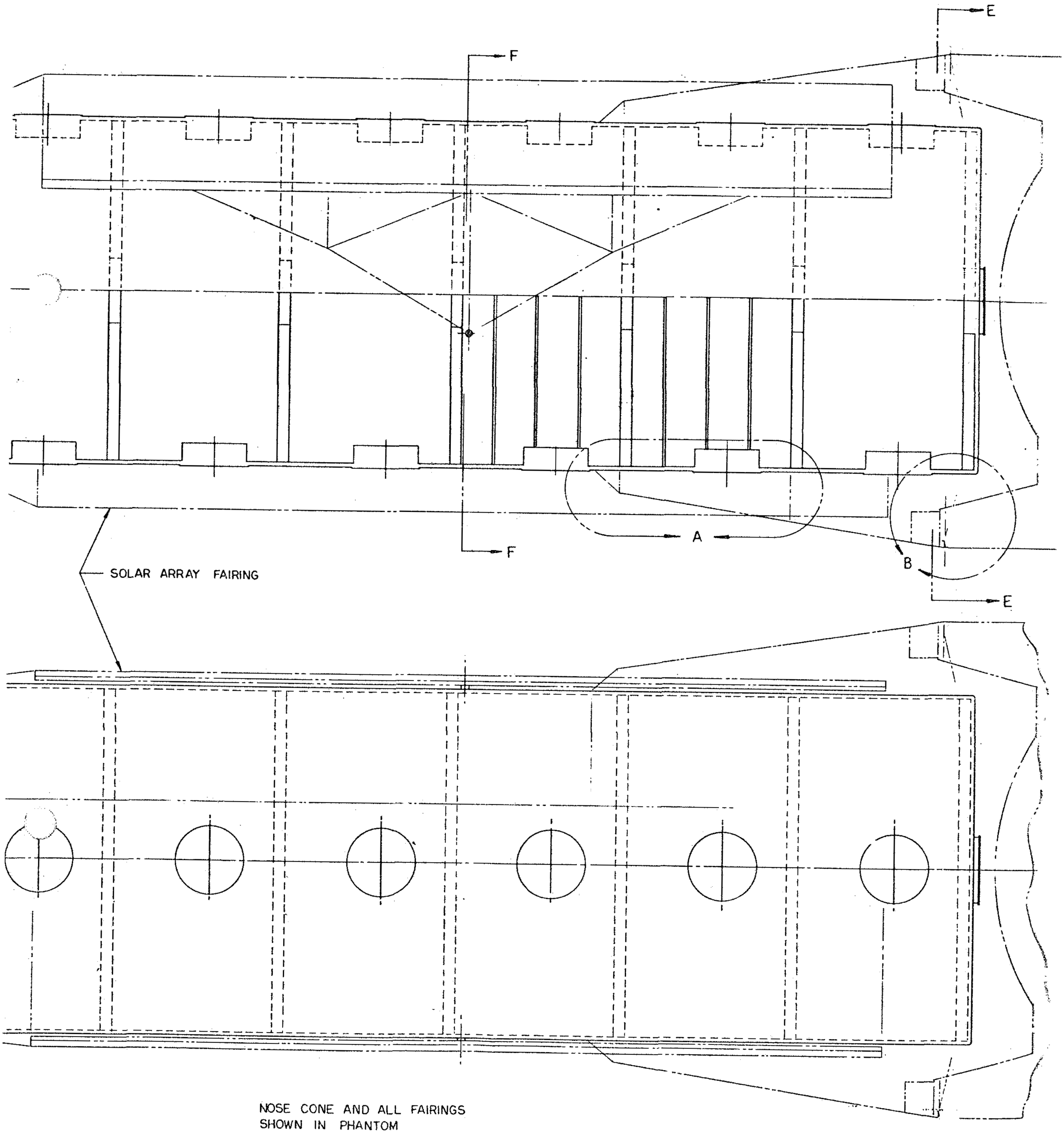


FIG. 3-21 INTERIM STATION STRUCTURE

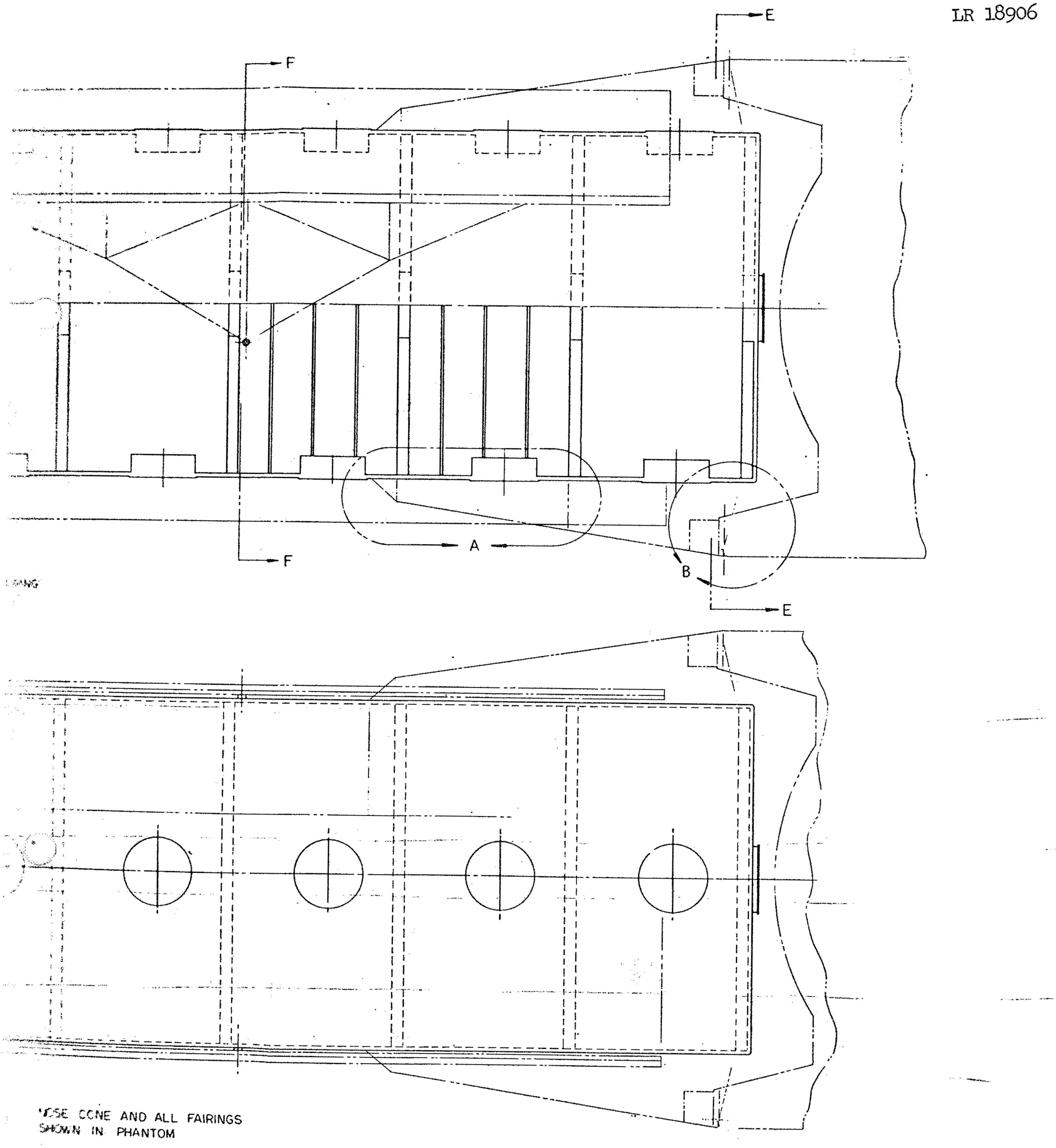
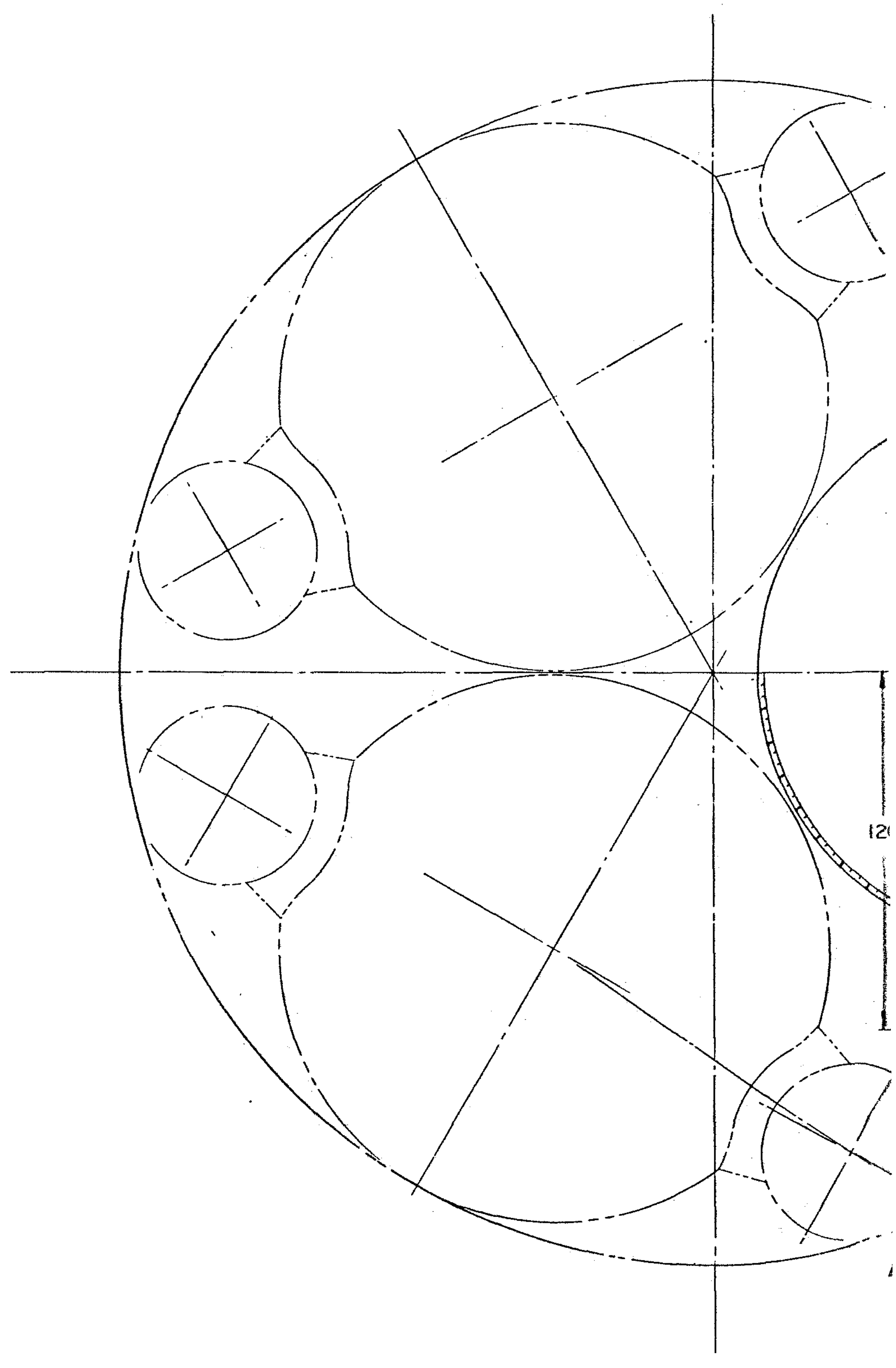
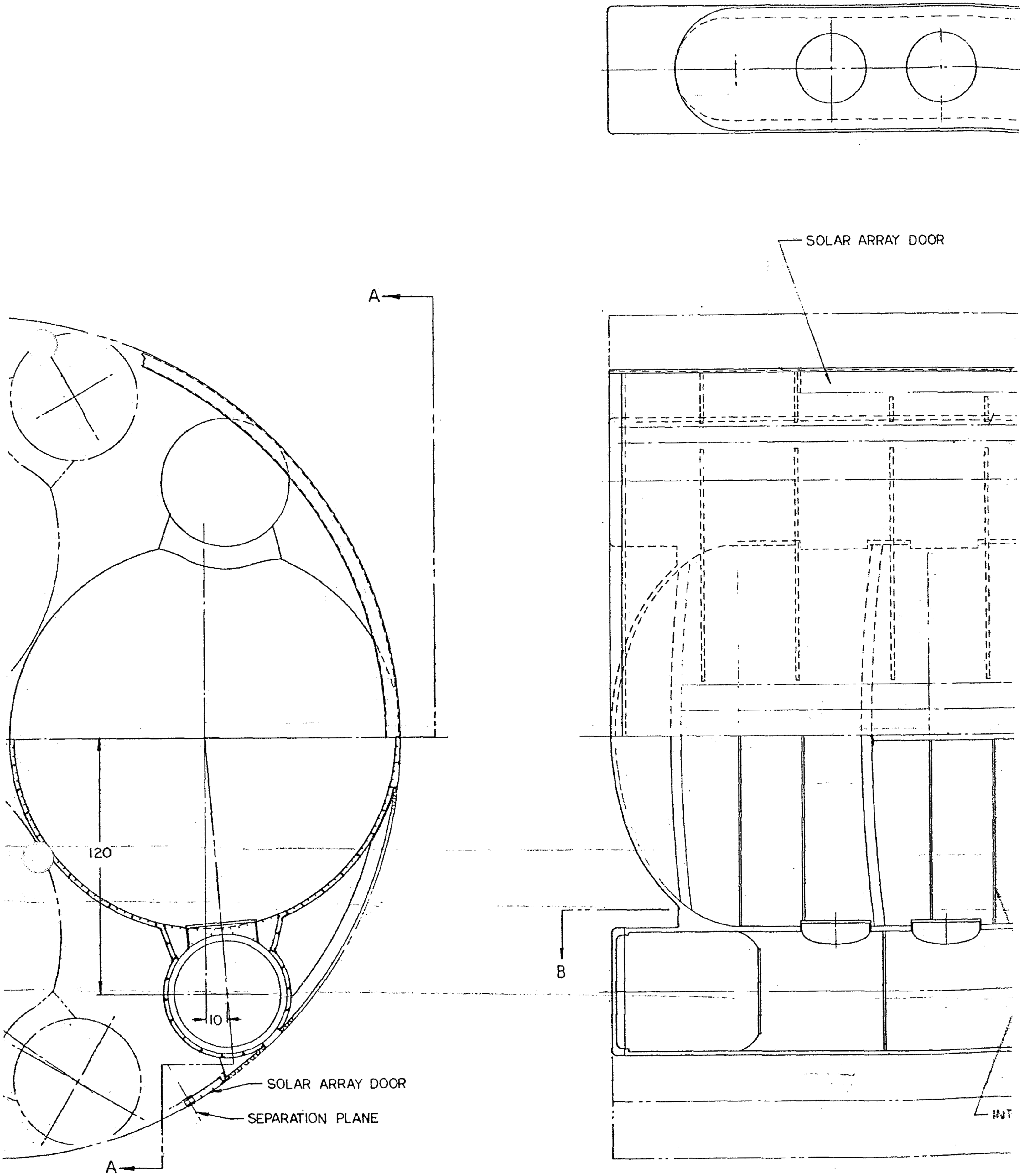
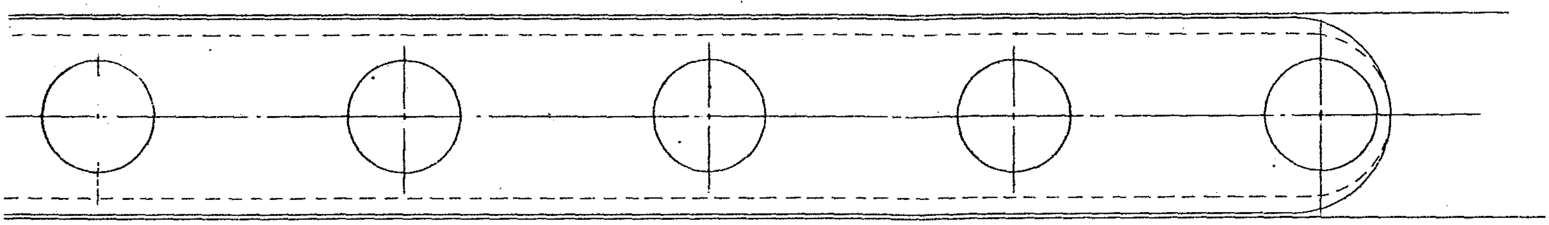


FIG. 3-21 INTERIM STATION STRUCTURE


12

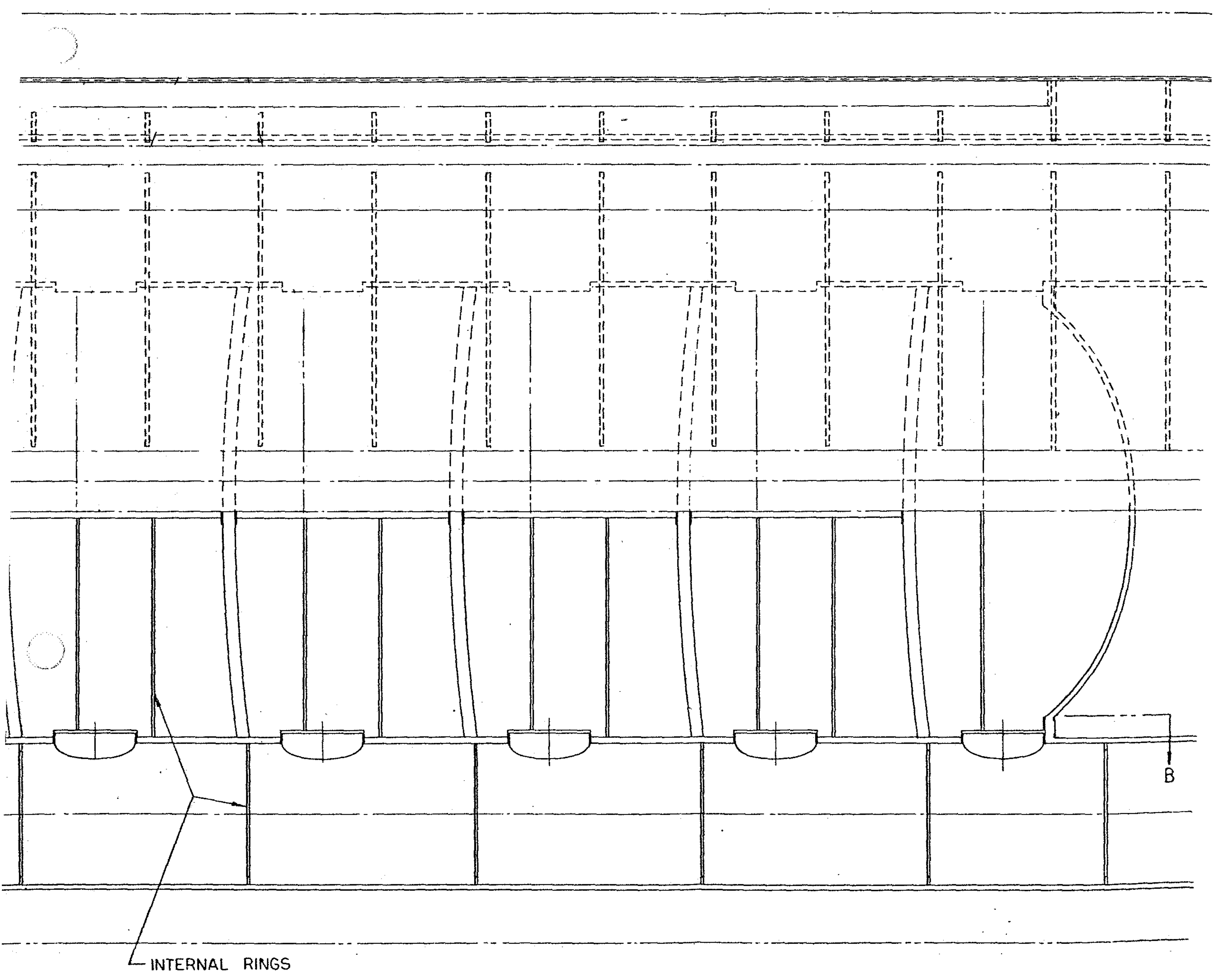


SOLAR ARRAY DOOR
A
120
10
SOLAR ARRAY DOOR
SEPARATION PLANE
A
B
INT



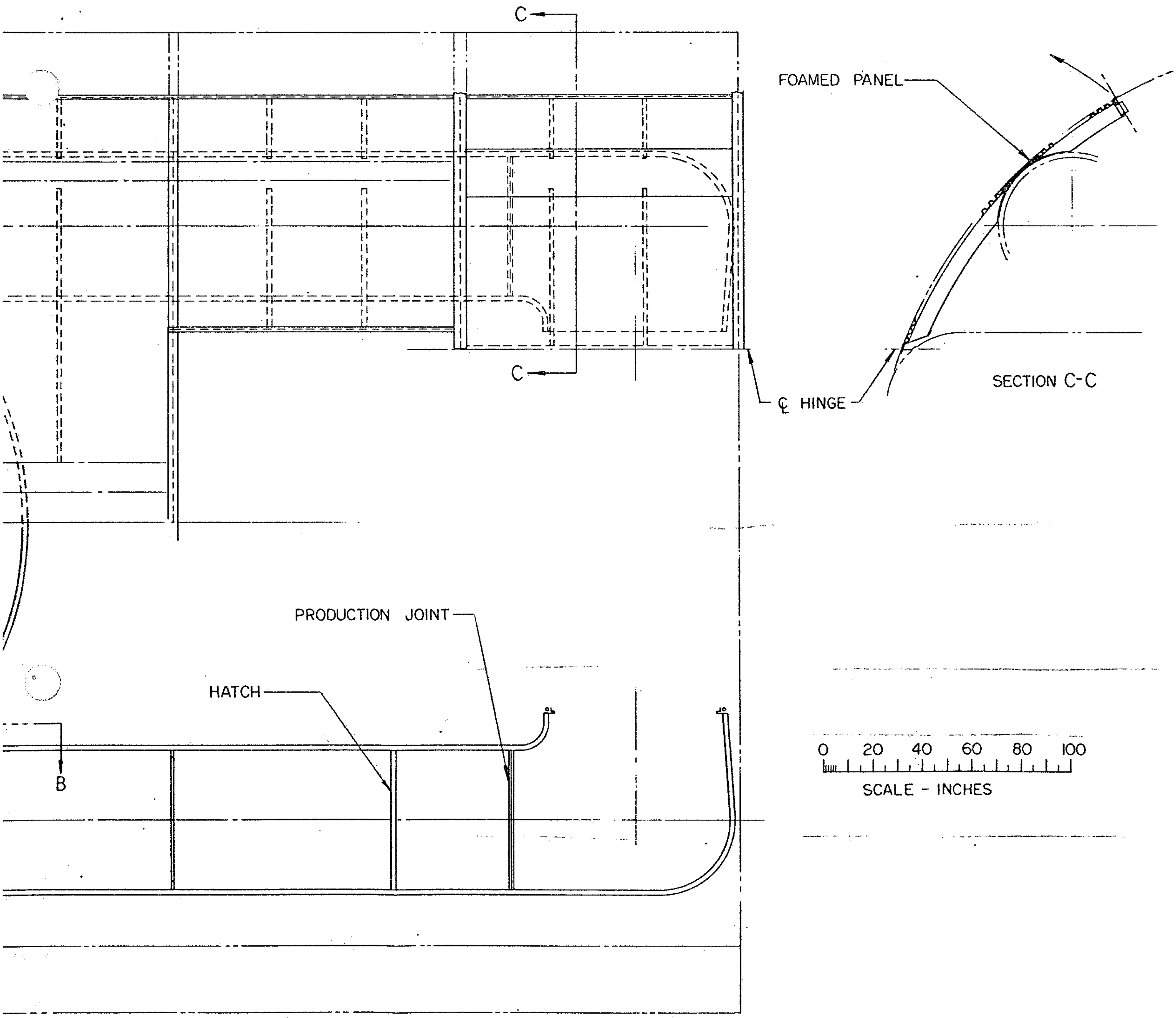
SECTION B-B

:AY DOOR

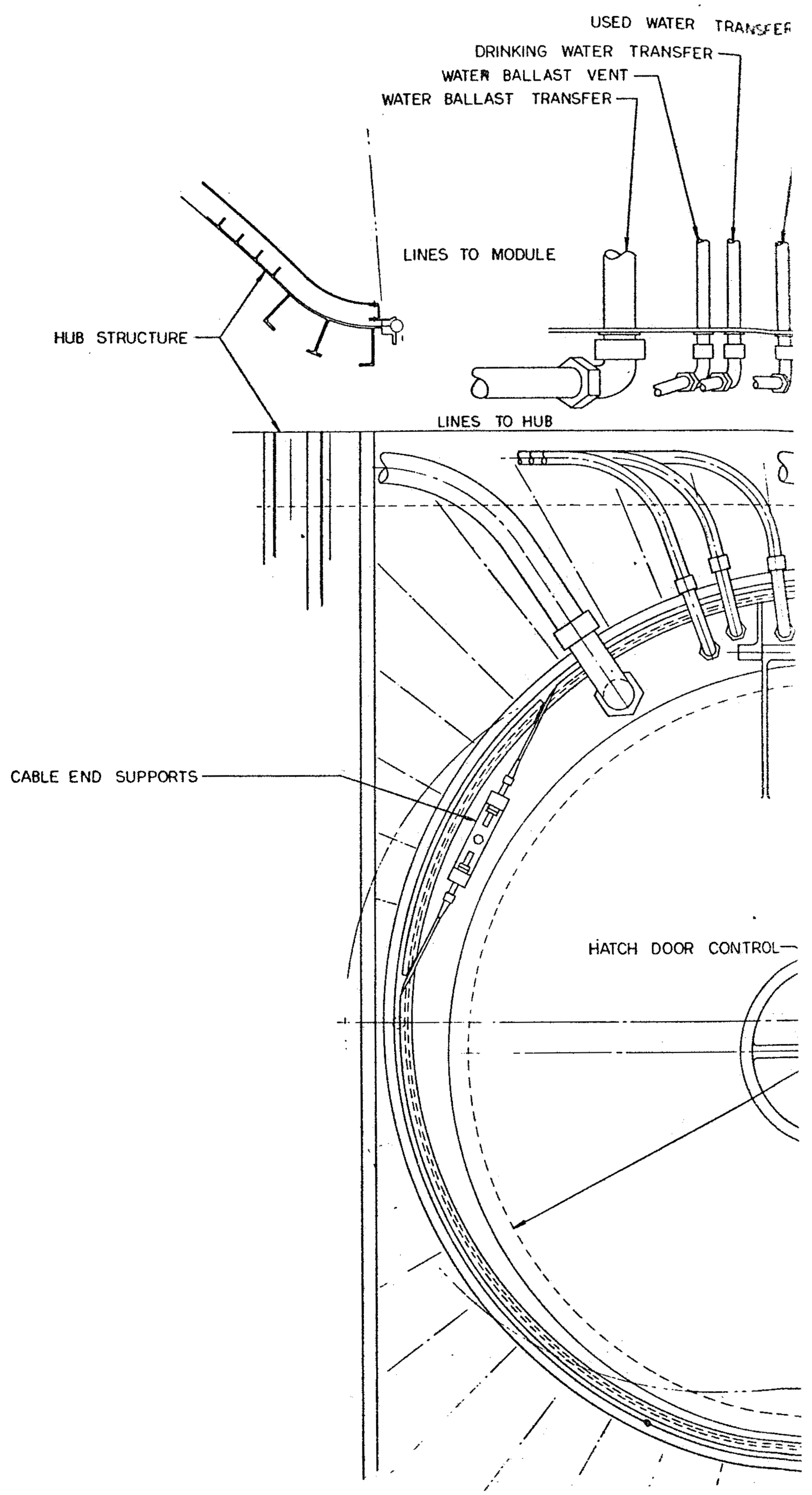


SECTION A-A

FIG. 3-22 M



3-22 MODULE AND ACCESS TUBE STRUCTURE, OPERATIONAL STATION



USED WATER TRANSFER
DRINKING WATER TRANSFER
WATER BALLAST VENT
WATER BALLAST TRANSFER
LINES TO MODULE
HUB STRUCTURE
LINES TO HUB
CABLE END SUPPORTS
HATCH DOOR CONTROL

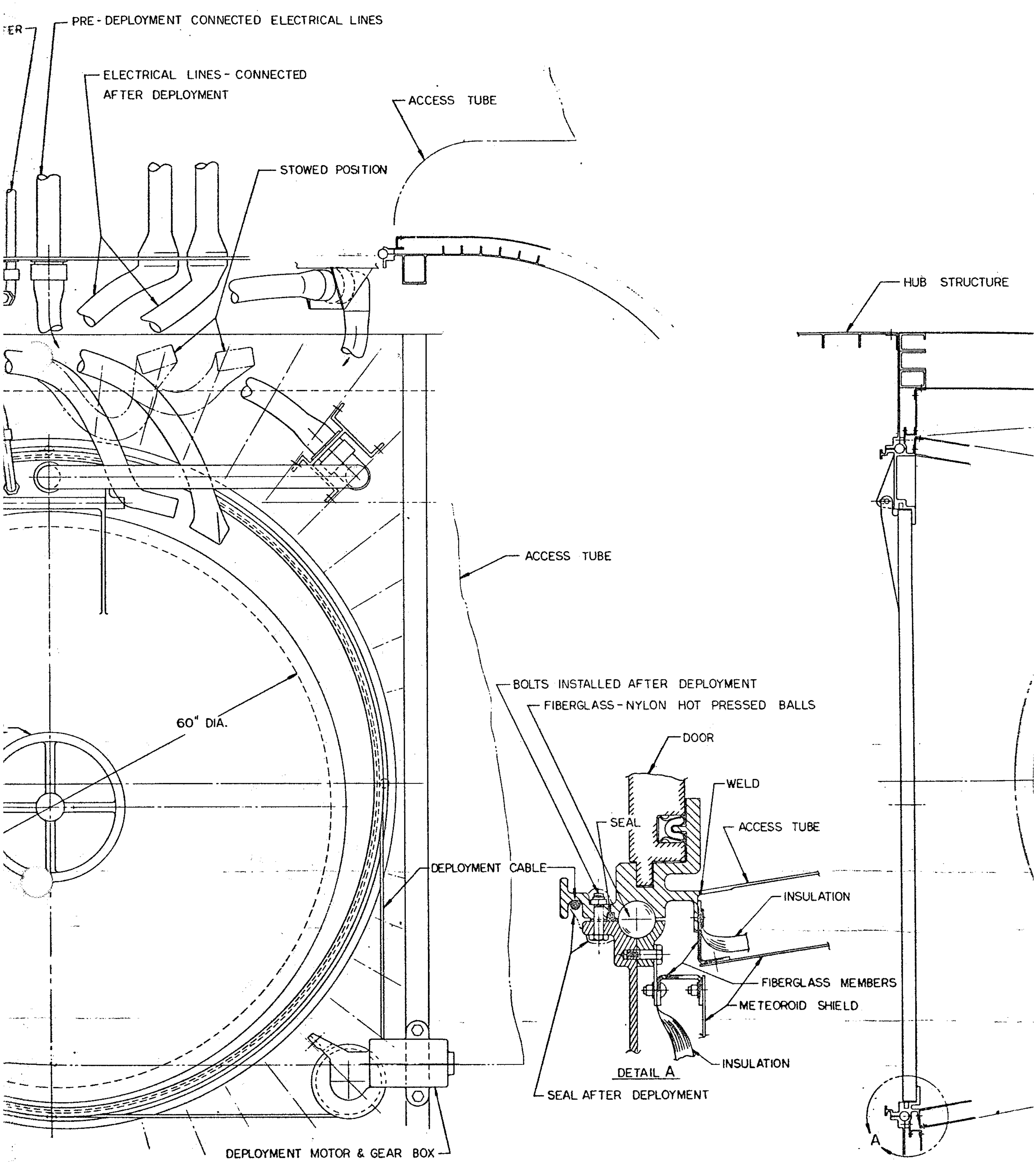

PRE-DEPLOYMENT CONNECTED ELECTRICAL LINES
ELECTRICAL LINES - CONNECTED AFTER DEPLOYMENT
ACCESS TUBE
STOWED POSITION
HUB STRUCTURE
ACCESS TUBE
BOLTS INSTALLED AFTER DEPLOYMENT
FIBERGLASS - NYLON HOT PRESSED BALLS
60" DIA.
DOOR
WELD
SEAL
ACCESS TUBE
DEPLOYMENT CABLE
INSULATION
FIBERGLASS MEMBERS
METEOROID SHIELD
INSULATION
DETAIL A
SEAL AFTER DEPLOYMENT
DEPLOYMENT MOTOR & GEAR BOX
A

FIG. 3-

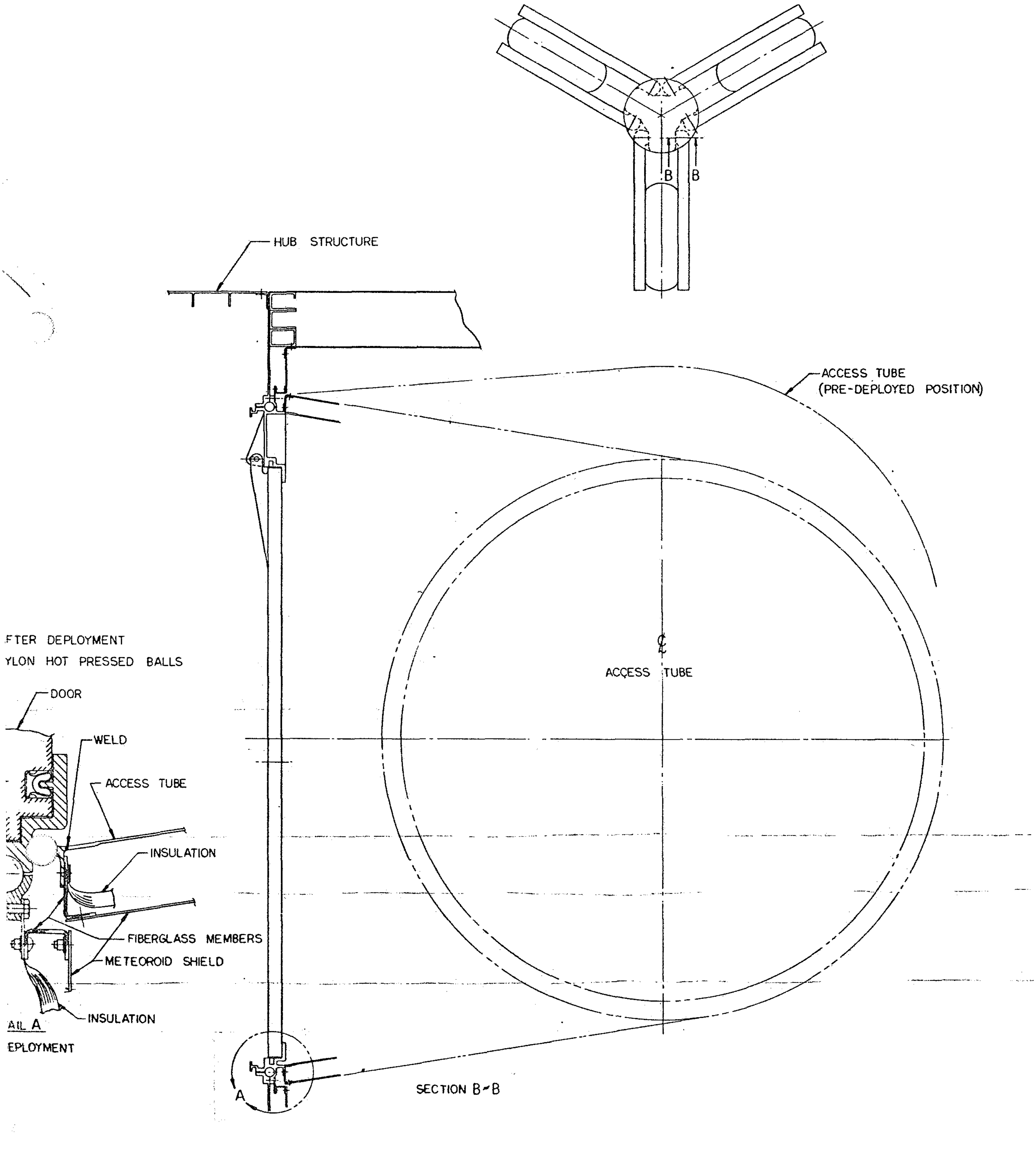
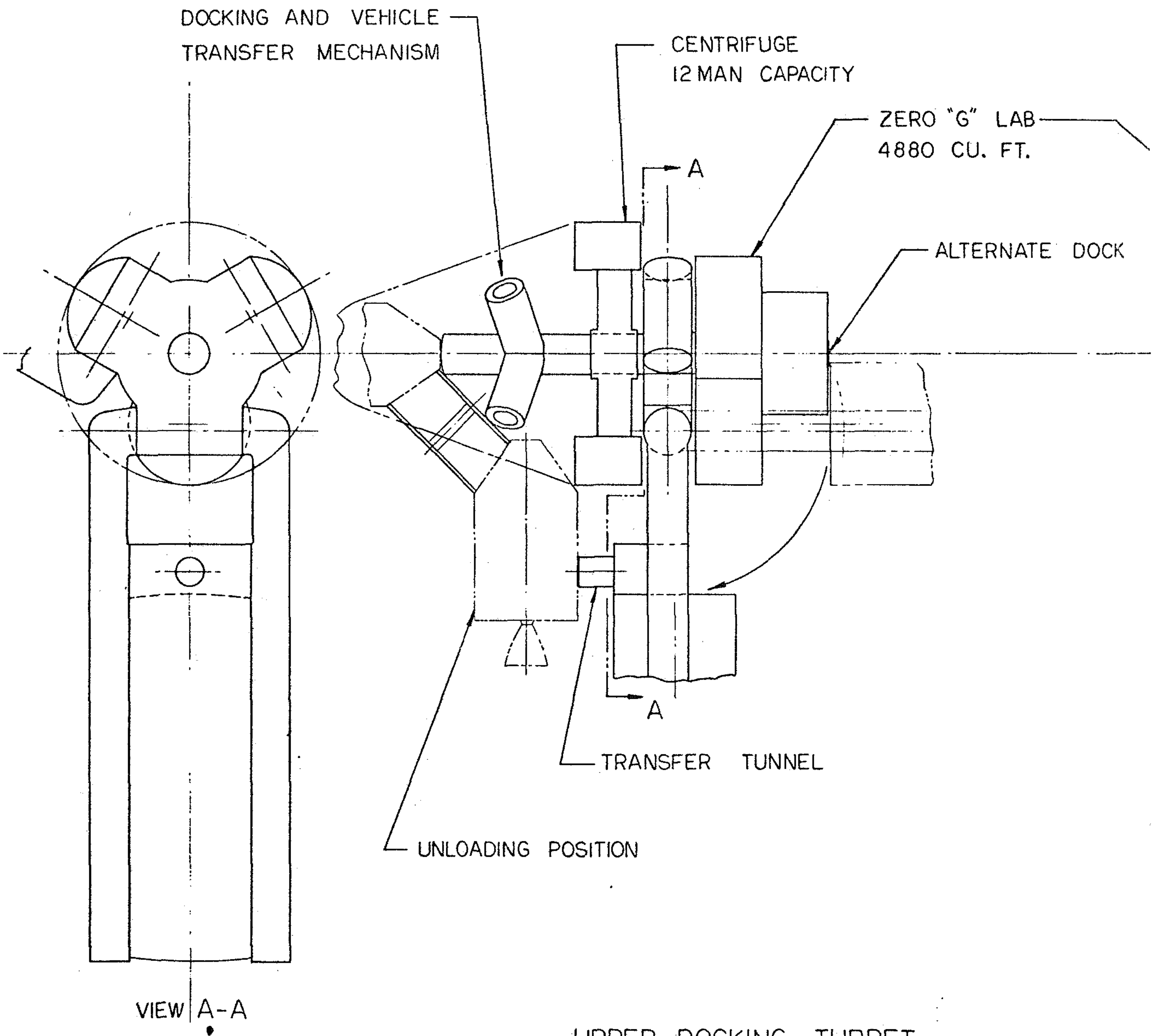
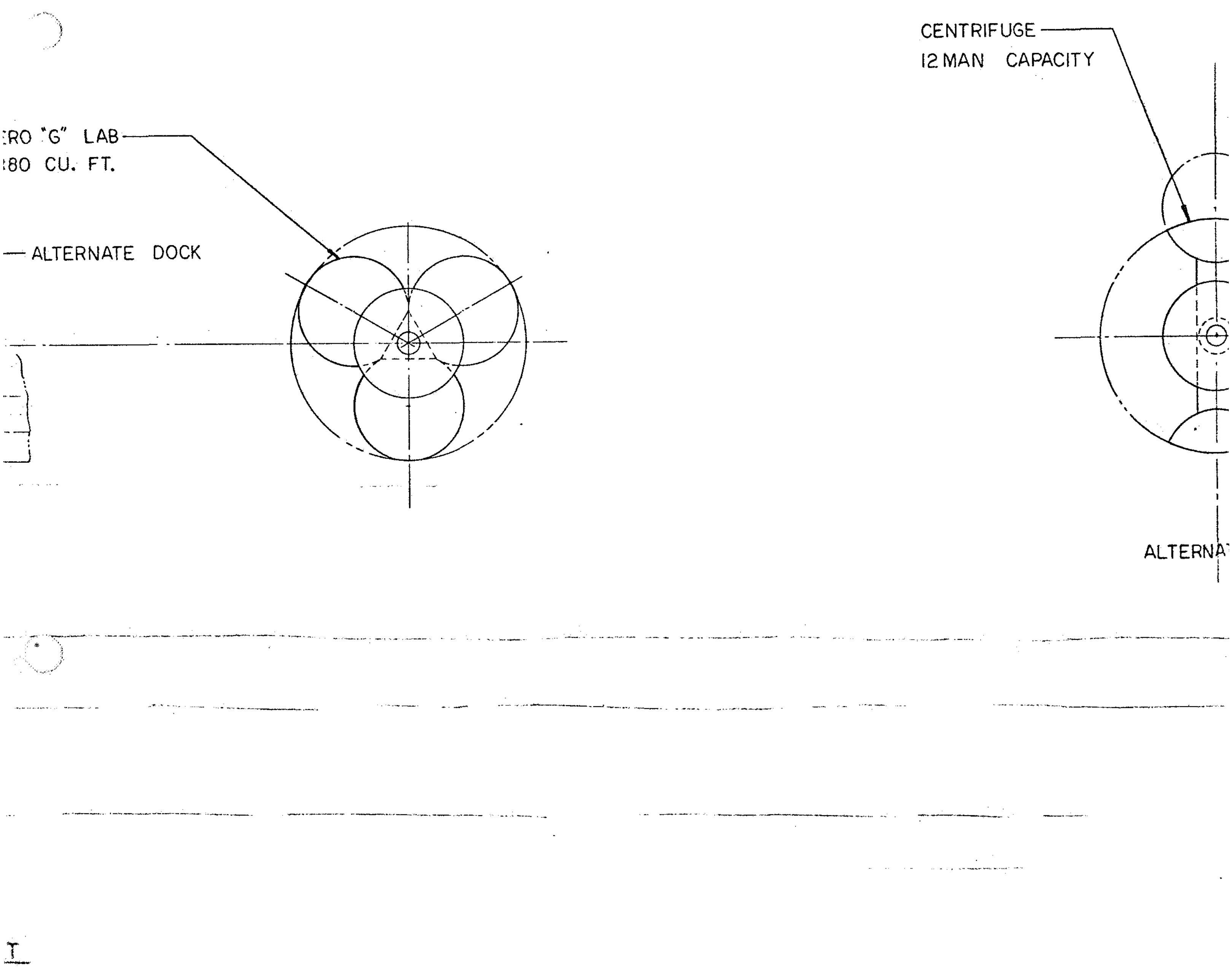


FIG. 3-23 HUB-MODULE INTERFACE, OPERATIONAL STATION



UPPER DOCKING TURRET



:RO "G" LAB
:80 CU. FT.
ALTERNATE DOCK
CENTRIFUGE
12 MAN CAPACITY
ALTERNA

FIG. 3

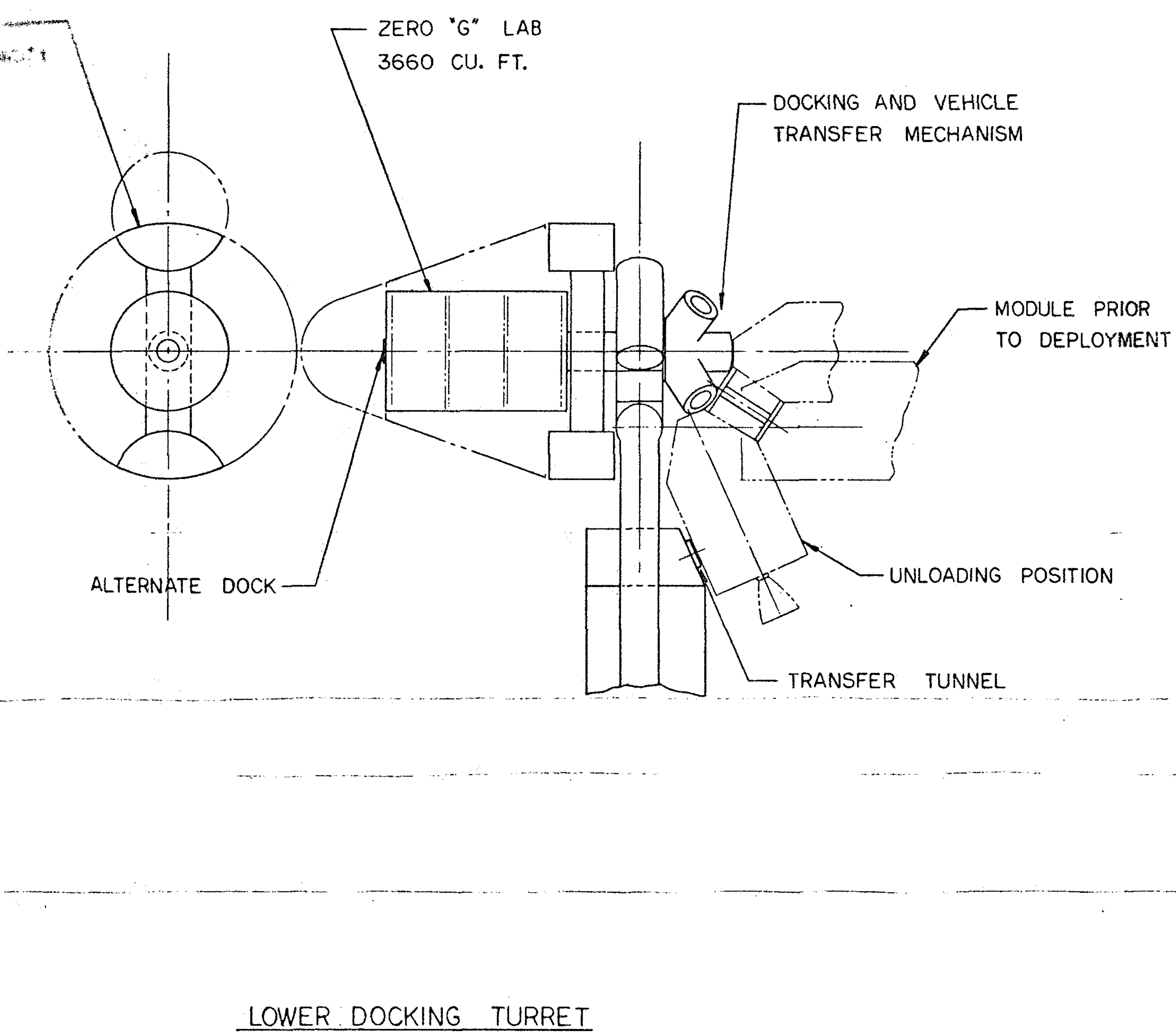
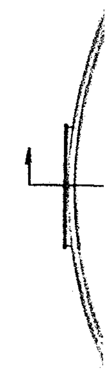
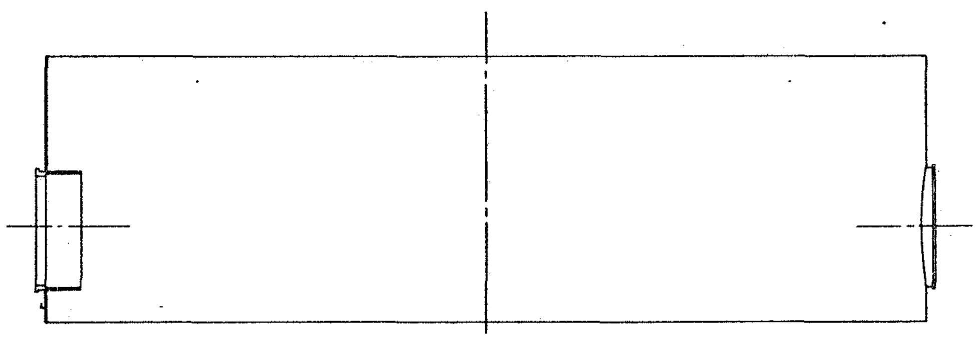
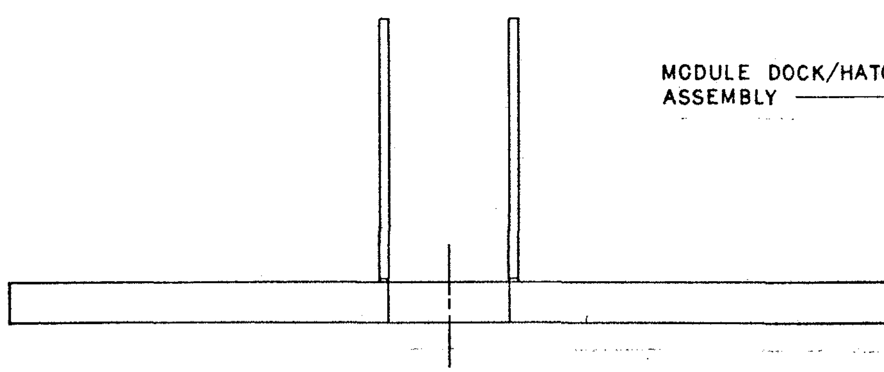


FIG. 3-24 HUB CONFIGURATIONS, OPERATIONAL STATION





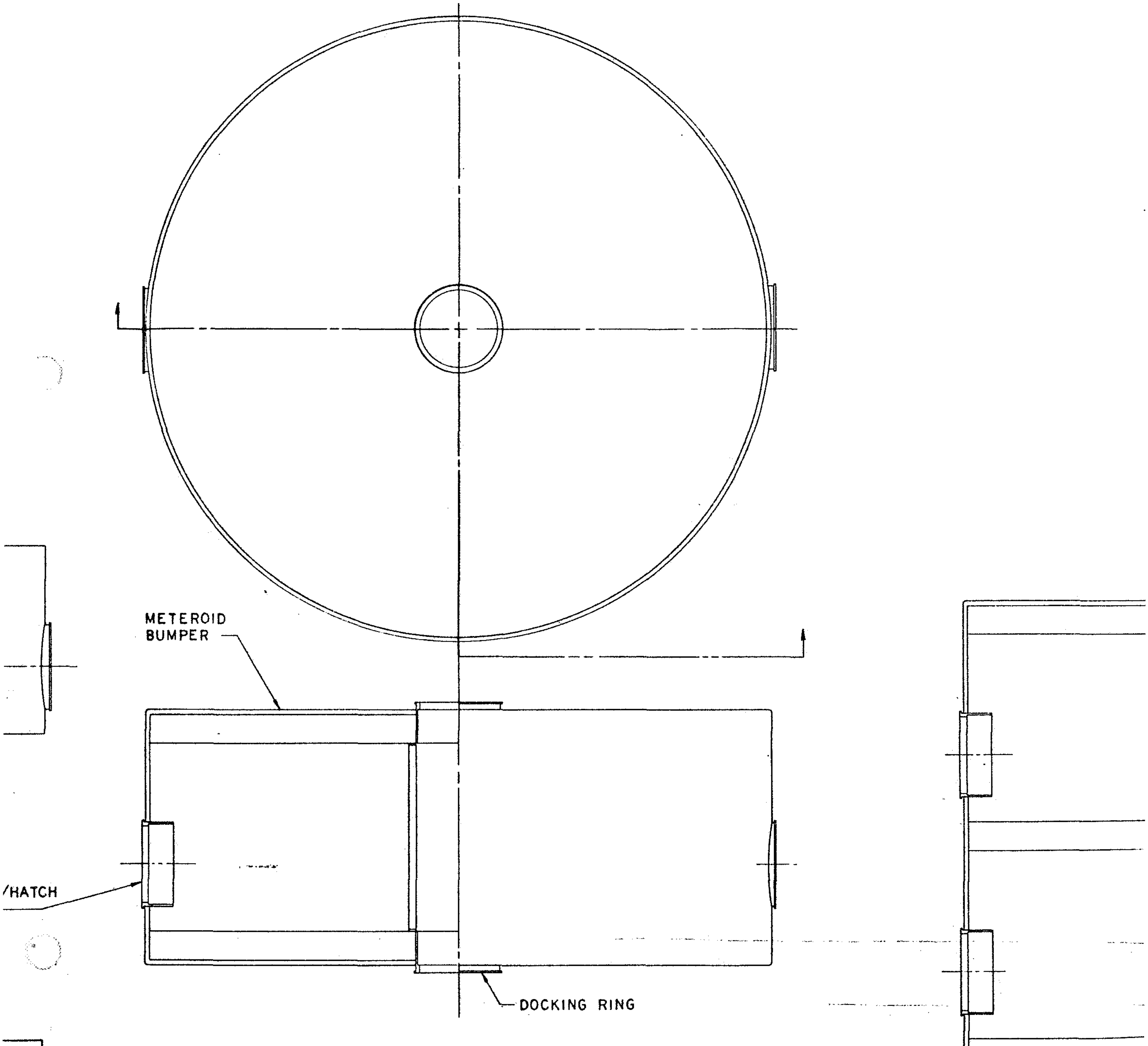
MODULE BARREL ASSEMBLY



PRESSURE FLOOR & INTERCONNECT ASSEMBLY

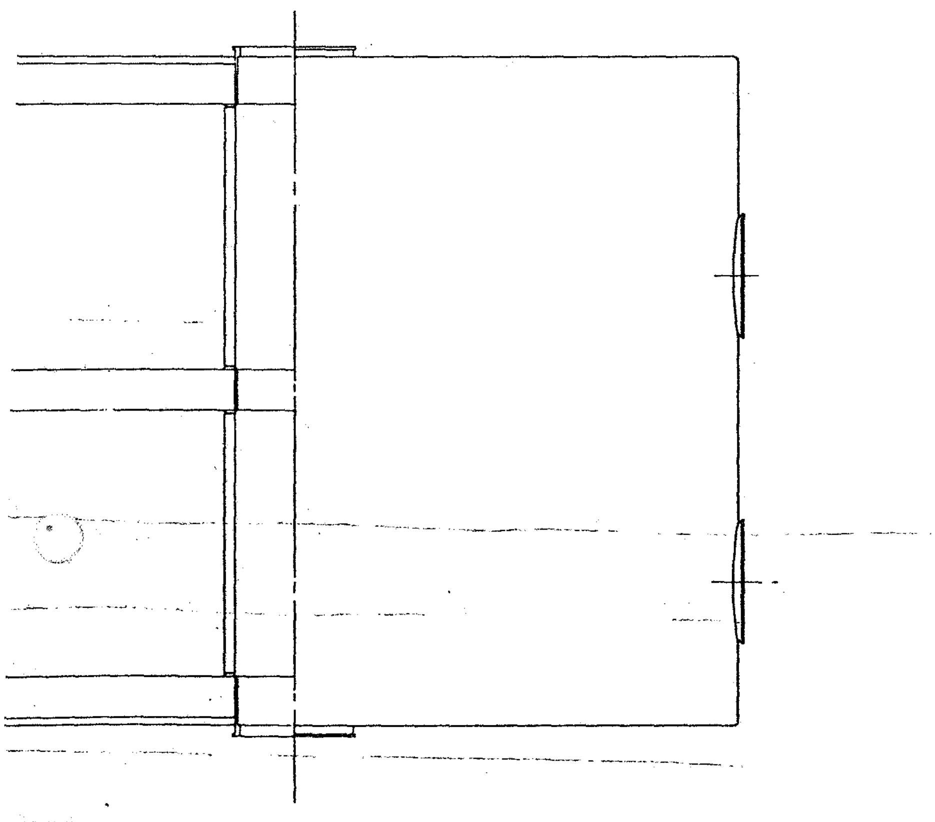
ME
BU

MODULE DOCK/HATCH
ASSEMBLY

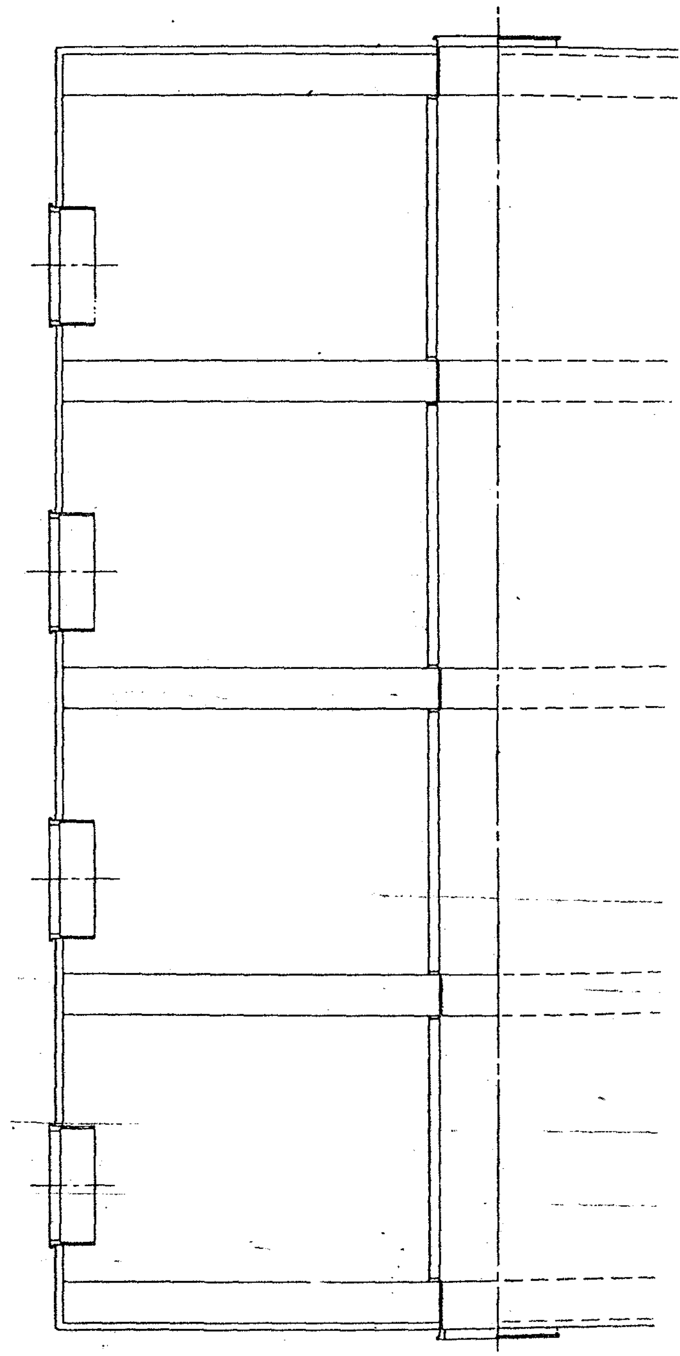


SINGLE COMPARTMENT LABORATORY ASSEMBLY

DOUBLE



DOUBLE COMPARTMENT LABORATORY ASSEMBLY



FOUR COMPARTMENT LABORATORY AS

FIG. 3-25 SEQUENTIAL EVOLUTION, 260-INCH DIAMETER MOD

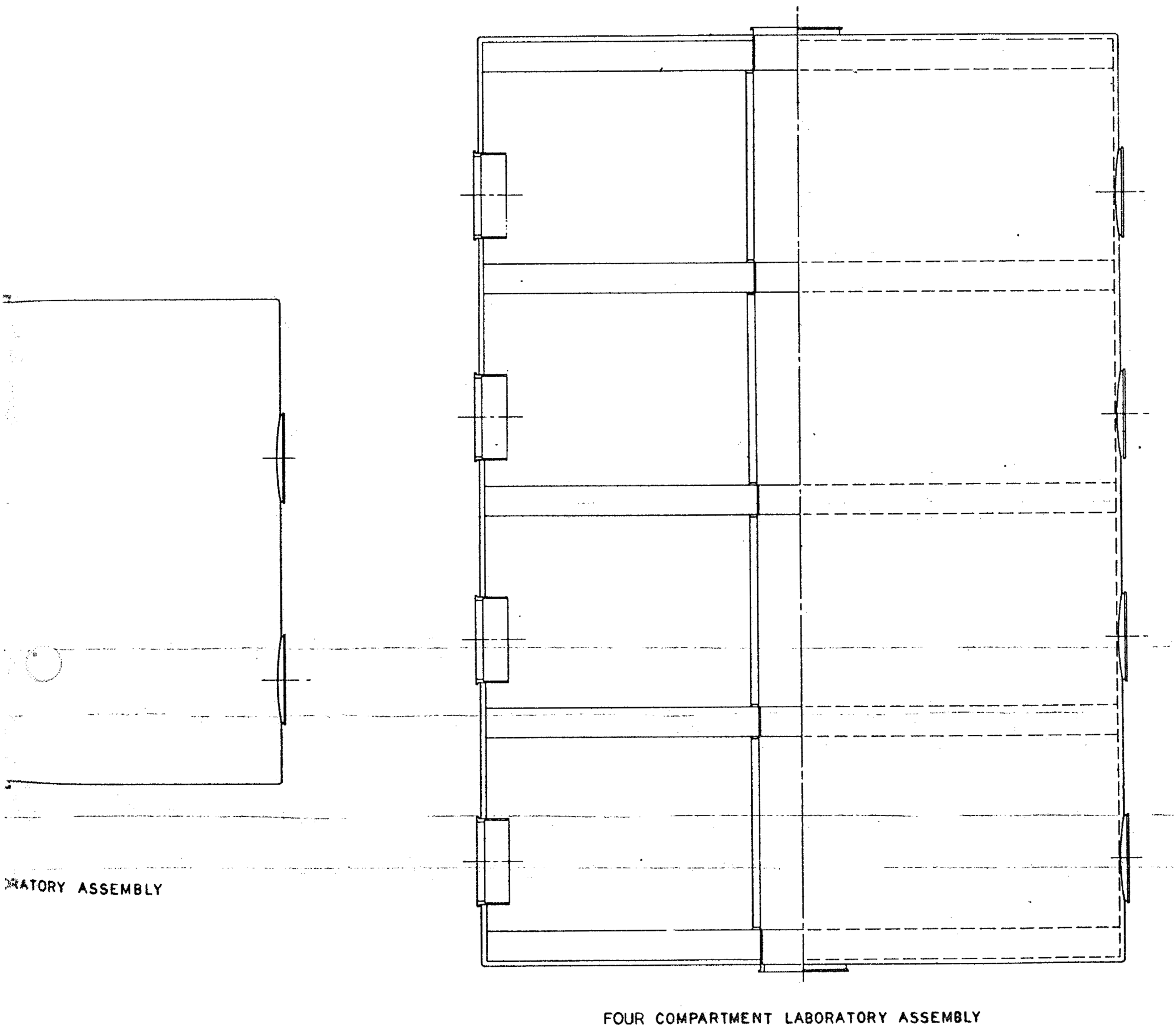
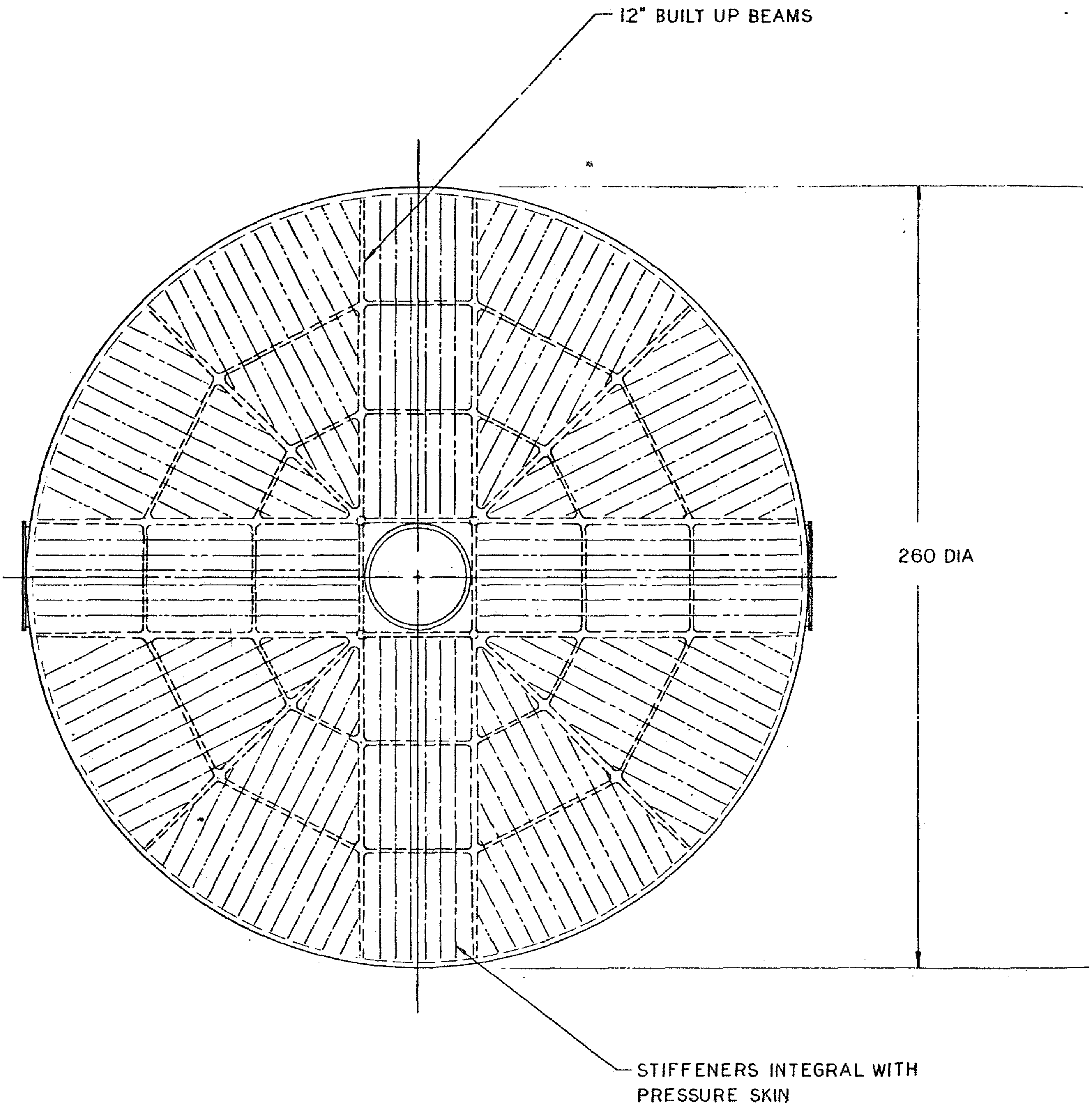
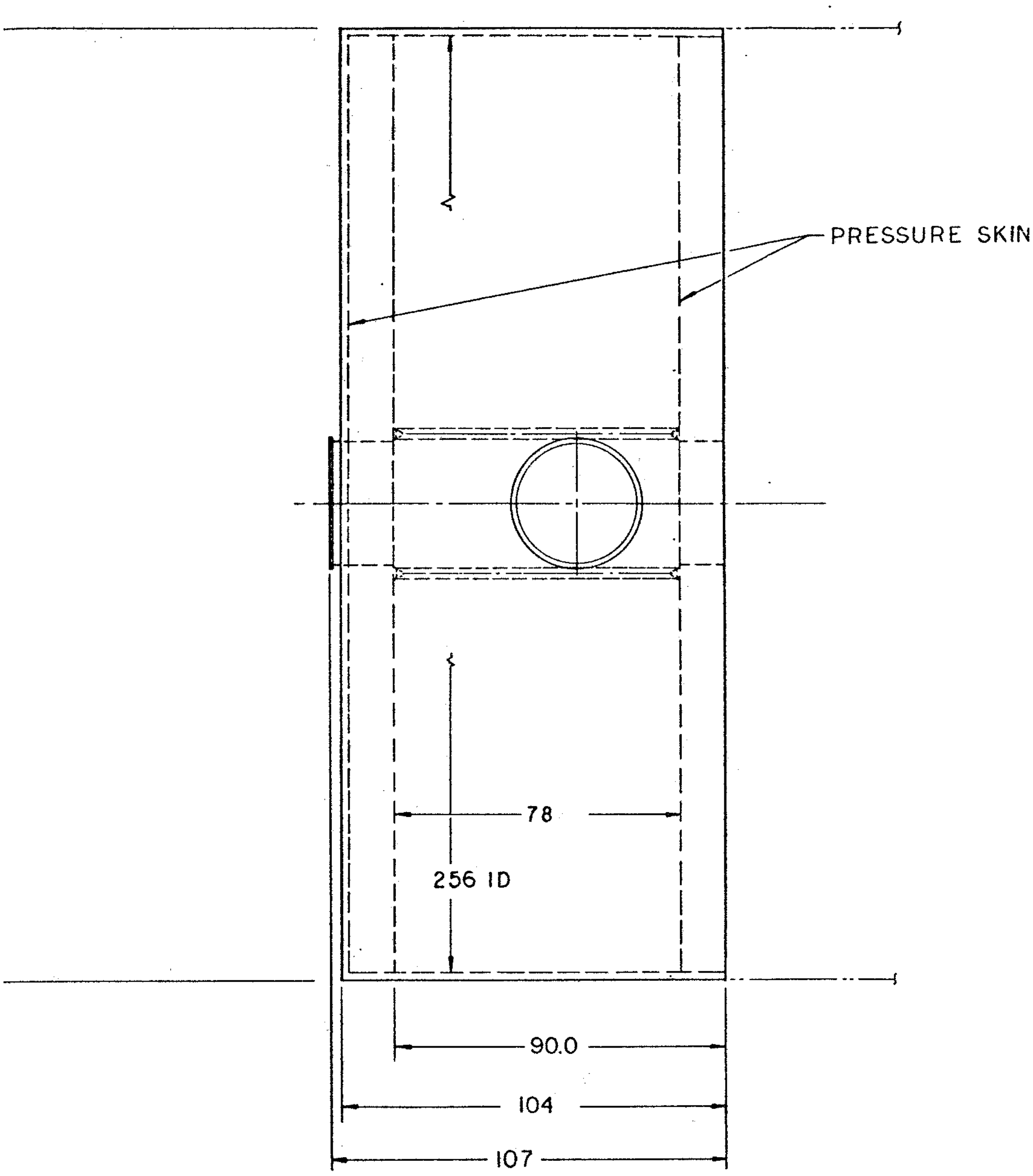


FIG. 3-25 SEQUENTIAL EVOLUTION, 260-INCH DIAMETER MODULAR CONCEPT


12" BUILT UP BEAMS
260 DIA
STIFFENERS INTEGRAL WITH
PRESSURE SKIN



NOTE: STRUCTURAL DETAIL TO BE SIMILAR
TO THAT OF THE 183" DIA / 8" BEAMS

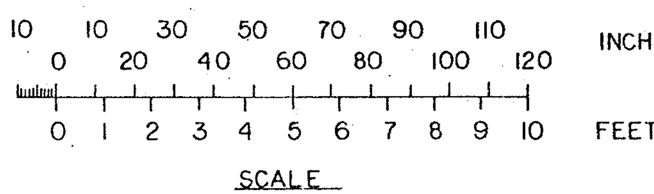


FIG. 3-26 STRUCTURE, 260-INCH DIAMETER MODULE

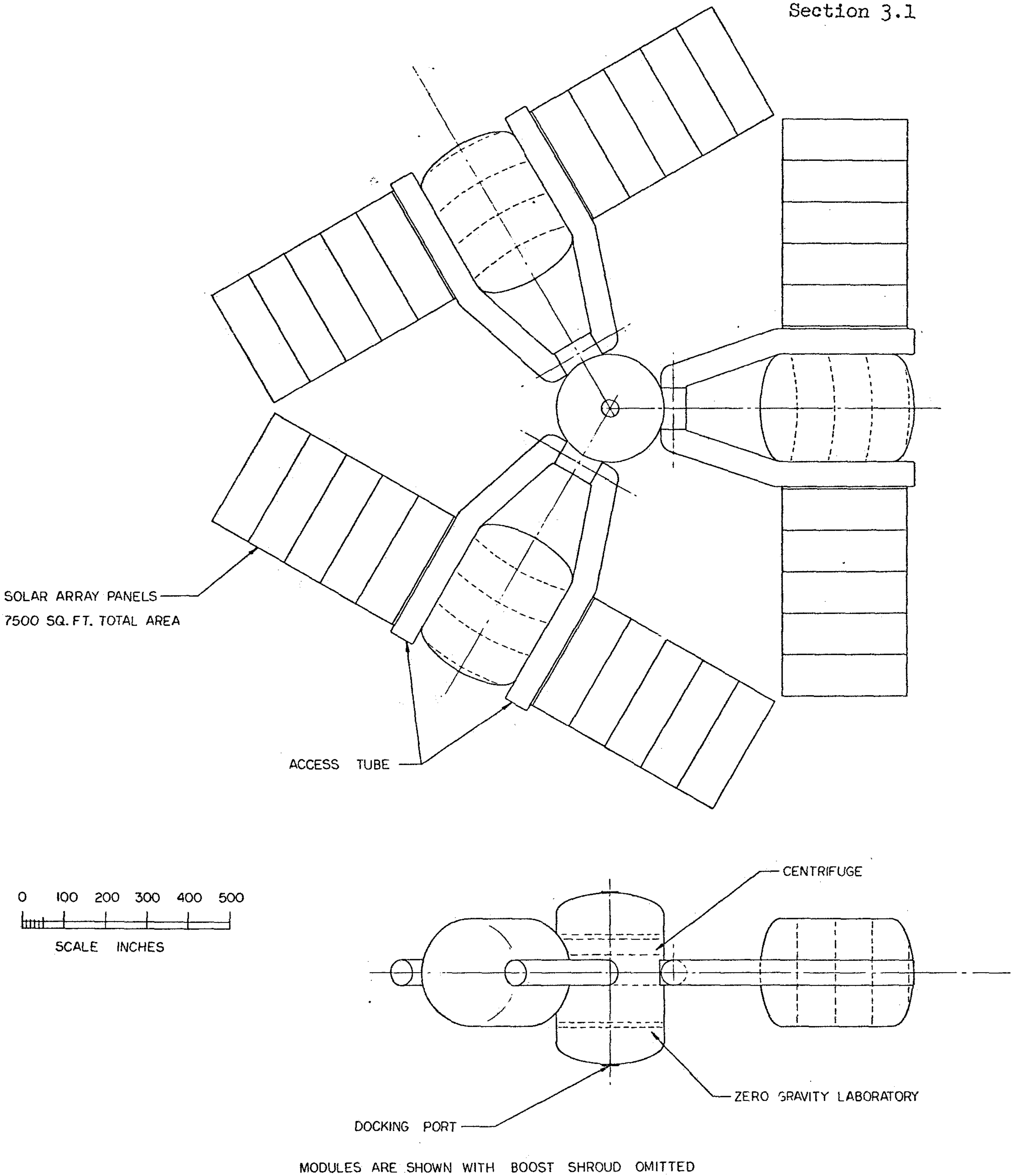
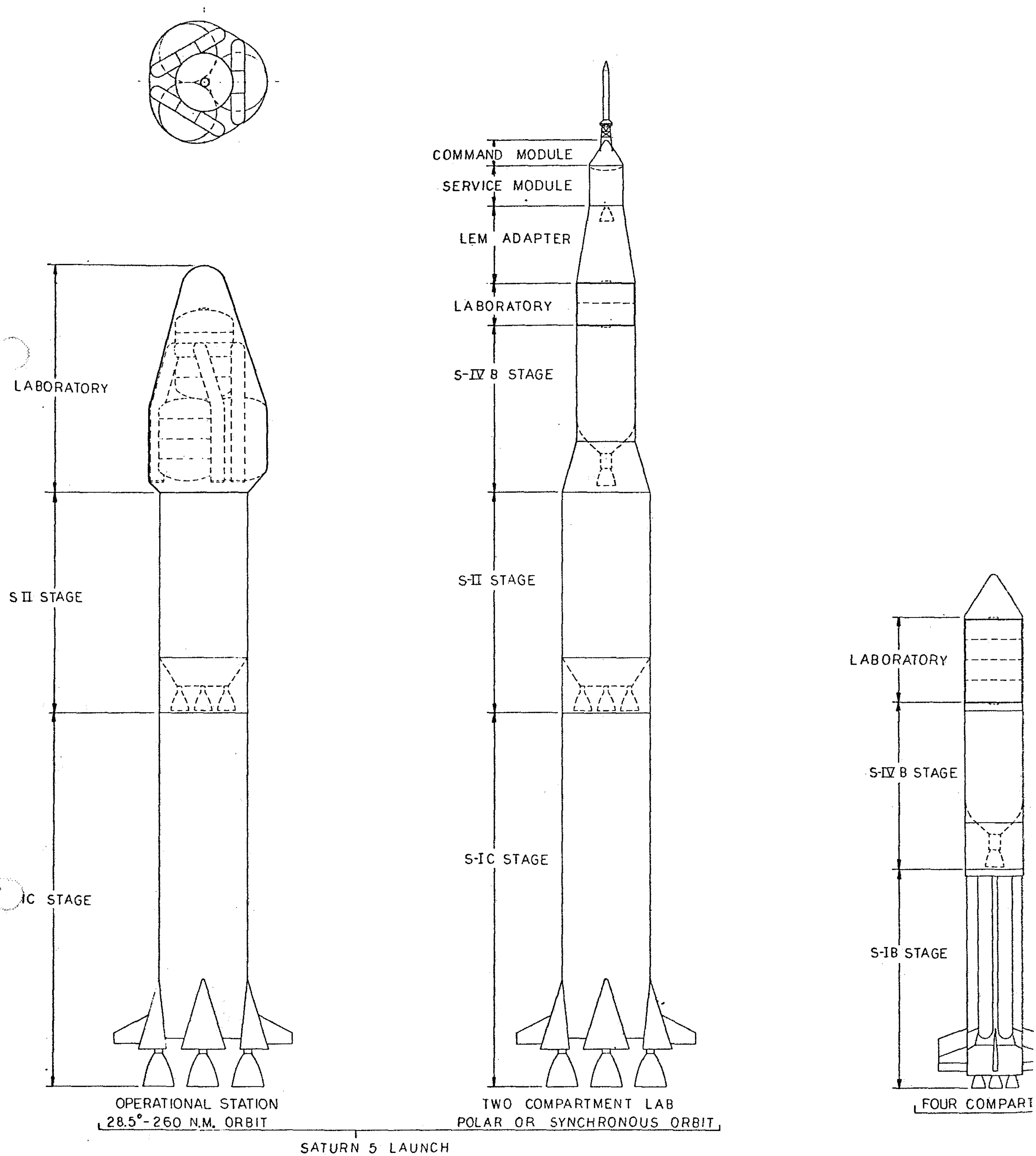


FIG. 3-27 ROTATING SPACE STATION, 260-INCH DIAMETER MODULES


COMMAND MODULE
SERVICE MODULE
LEM ADAPTER
LABORATORY
S-IV B STAGE
S-II STAGE
S-IC STAGE
LABORATORY
S II STAGE
IC STAGE
LABORATORY
S-IV B STAGE
S-IB STAGE
OPERATIONAL STATION
28.5°-260 N.M. ORBIT
TWO COMPARTMENT LAB
POLAR OR SYNCHRONOUS ORBIT
SATURN 5 LAUNCH
FOUR COMPART

FI

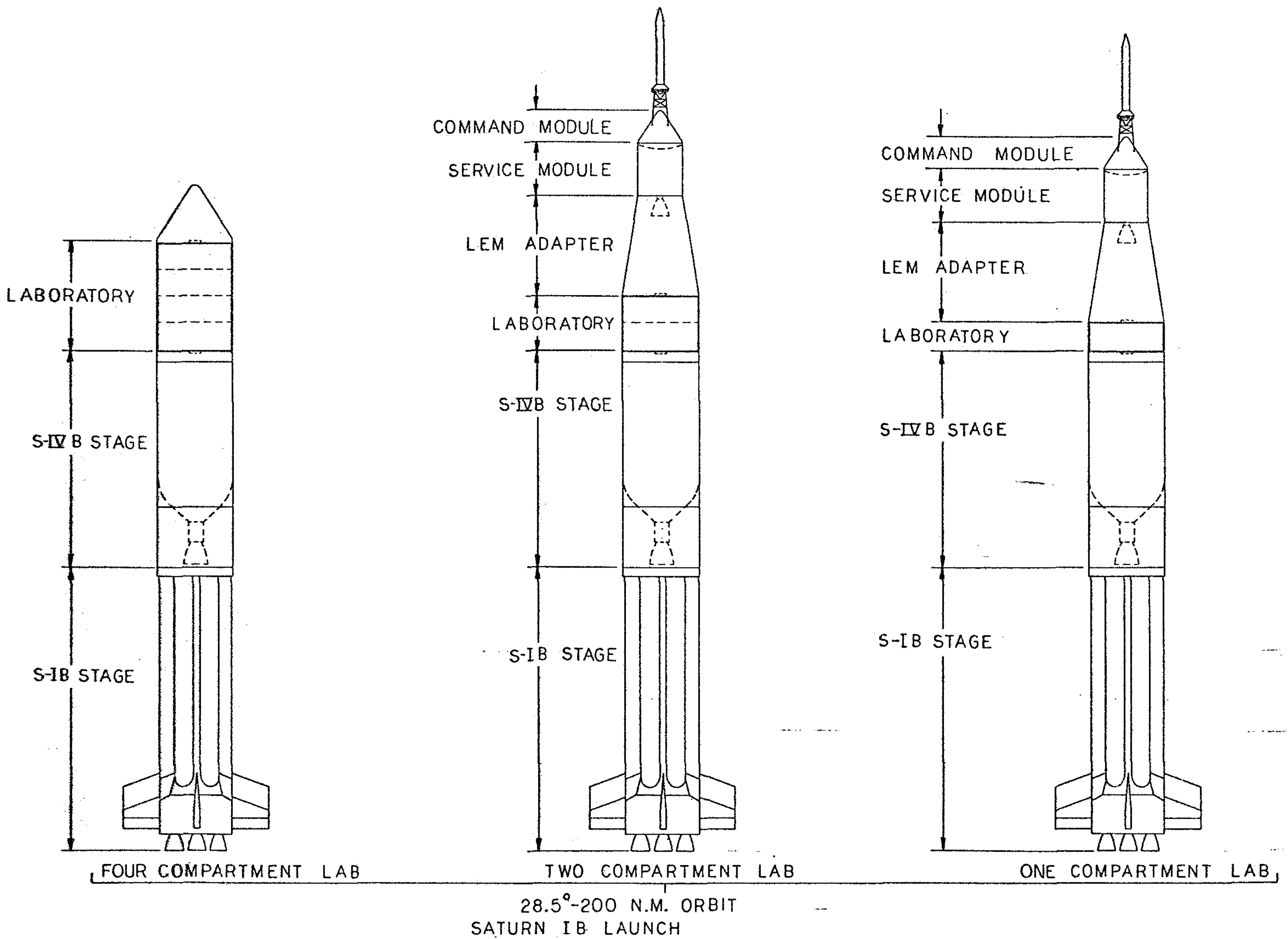


FIG. 3-28 LAUNCH CONFIGURATIONS, 260-INCH DIAMETER MODULAR CONCEPTS

3.2 RADIATION SHIELDING

The following analysis is concerned with the protection of personnel from the high energy space radiation in the Modular Multipurpose Space Station configurations.

Two specific candidate design conditions have been investigated (Sections 3.2.1 and 3.2.2):

- a polar orbit mission for 3 to 12 months at 200 n.mile altitude.
- a 30-deg inclination, synchronous altitude mission for 3 to 12 months time.

The various individual space radiation components including geomagnetically trapped particles, solar particles, and cosmic rays are discussed. The radiation shielding required in each of the above two missions is calculated for mission times of 3, 6, and 12 months. Shield weight estimates are given for two different methods of shielding, namely shielding of the entire space station and local personnel shielding.

The radiation environment and the required radiation shielding for low inclination earth orbit missions is discussed in Section 3.3 of the FY-63 study, "Study of a Rotating Manned Orbital Space Station" (Lockheed Report 17502).

Throughout the space radiation analysis, the space environment data used was that furnished by the NASA. Where no specific information on a particular radiation component was available, the required data were obtained from the open literature.

The space radiation shield requirements for the Two Compartment Laboratory under two design conditions have been computed. It is found that the nuclear particles and photons present an extreme hazard in the unshielded condition. The shielding required to reduce this hazard is considerable and represents shield weights of up to 5000 lb or more depending on the mission. It is shown that these shields may be reduced considerably by the use of local body shielding.

The allowable radiation dosage limits have been defined by the NASA. These limits are applicable to the total amount of radiation received from all sources during the time spent in the space stations, and are shown in Table 3-2.

Table 3-2

MAXIMUM ALLOWABLE DOSE RATE

Critical Body Organ	Average Yearly Dose (Rad)
Eyes	27
Blood forming organs	54
Feet, ankles and hands	559
Skin of whole body	233

3.2.1 Space Radiation Shielding - Polar Orbit

The space radiation environment and shielding requirements are discussed in Sections 3.2.1.1 and 3.2.1.2, respectively.

3.2.1.1 Space Radiation Environment

Galactic Cosmic Rays. The radiation absorbed dose due to the extremely high energy cosmic rays is estimated to be 1 rad per year for the polar orbit. Due to the protection of the earth at this low (200 n. mile) altitude, the cosmic ray dose is reduced by more than a factor of four over the synchronous orbit case discussed subsequently in Section 3.2.2.

Trapped Electrons. The electron spectrum assumed in this study for a 200 n. mile, 90-deg inclination orbit is shown in Fig. 3-29 (Ref. 3.2-8). Approximately 10^8 electrons/cm^2 are intercepted per day in this orbit. This results in a dose of 1.68 rad/day inside the Two-Compartment Laboratory wall structure shown in Fig. 3-30. Thus, trapped electron dose accumulates at a rapid rate, and for long duration missions (16 days or more) radiation shielding in addition to wall structure must be provided to maintain an absorbed dose limit of 27 rad/mission to the eye.

Bremsstrahlung. Low altitude bremsstrahlung contributes insignificantly to the total dose and therefore no additional shielding is required for this component.

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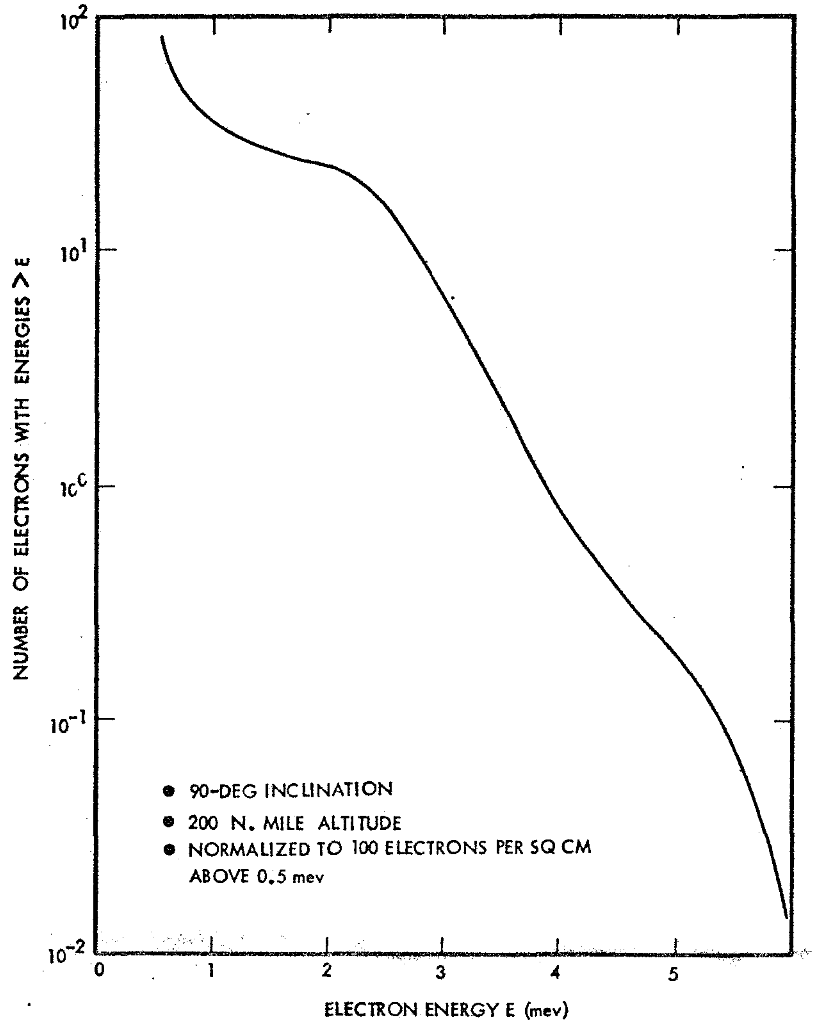

FIGURE 3-29 LOW ALTITUDE INTEGRAL ELECTRON SPECTRUM

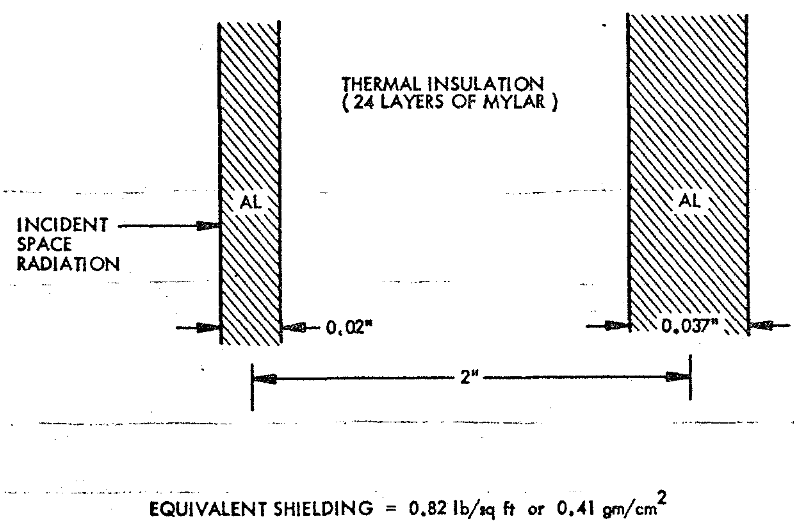

FIGURE 3-30 LABORATORY WALL STRUCTURE

Trapped Protons. An evaluation has been made of the trapped proton dose for a 200 n. mile polar circular orbit. For this effort, a Freden-White proton energy spectrum was assumed (Ref. 3.2-1). Approximately 9×10^5 protons/cm^2-day are intercepted in this orbit. This results in a dose of 0.12 rad/day inside the laboratory wall structure. The shielding required to reduce this dose to the required limits is included in Section 3.2.1.2.

Solar Protons. In low altitude orbits, the solar flare event protons are reduced by a factor of two as a correction for the time spent at low latitudes under the protection of the Van Allen belts. The results are shown in Table 3-3.

Table 3-3

NUMBER (N) OF SOLAR PROTONS INTERCEPTED (PROTONS/CM^2)

Probability That No More Than N* Protons Are Intercepted	3 Months	6 Months	12 Months
.90	1.4×10^9	3.2×10^9	5.9×10^9
.99	1.5×10^{10}	2.7×10^{10}	3.6×10^{10}
.999	8.1×10^{10}	1.3×10^{11}	1.5×10^{11}

*N is the number of protons with energy greater than 30 Mev. Quoted numbers are reduced by a factor of approximately 2 for low-altitude, high-inclination orbits.

Solar Alpha Particles. The absorbed radiation dose from solar alpha particles is included in the solar particle shielding given in Table 3-4.

Table 3-4.

ALUMINUM SHIELDING* REQUIRED IN A 200-N. MILE POLAR ORBIT FOR VARIOUS MISSION TIMES

Probability of Not Exceeding 100 Rads/Mission from Solar Particles	3 Months	6 Months	12 Months
0.90	.125 gm/cm^2	2.5 gm/cm^2	12 gm/cm^2

*Shielding for an active sun exposure of 100 rad/mission.

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CALIFORNIA COMPANY

3.2.1.2 Shield Requirements

Shielding Thicknesses. The combined dose absorbed to the eye from trapped electrons and trapped protons in the 200-n. mile polar orbit inside the laboratory wall structure is approximately 1.78 rad/day. For an absorbed dose limit of 27 rad/mission to the eye, a laboratory crew member is constrained to a mission time of approximately 15 days.

The space radiation shielding necessary to maintain mission times of 3, 6 and 12 months is shown in Table 3-5. Considered are the trapped belt particles, trapped belt secondary bremsstrahlung, and cosmic ray doses.

Table 3 -5

SHIELDING REQUIRED IN 200-N. MILE POLAR ORBIT DURING QUIET SOLAR CONDITIONS

Mission Time, (months)	Aluminum Shielding Requirements*		
	Total (gm/cm^2)	Wall Structure (gm/cm^2)	Added Shielding (gm/cm^2)
3	1.45	0.41	1.04
6	2.0	0.41	1.59
12	2.9	0.41	2.49

*For 27 rad/mission dose limit to the eye.

Table 3 -6 shows the shielding requirements imposed by solar flares for 200-n. mile polar orbit. In all cases except the three-month mission, the solar flare penalty is more than the penalty imposed by the trapped radiation. Thus no additional shielding is required to reduce the solar flare dose on a three-month mission if an emergency dose of 100 rad per mission is allowed.

Table 3-6

SHIELDING REQUIRED IN 200-N. MILE POLAR ORBIT
DURING ACTIVE SOLAR CONDITIONS

Mission Time, (months)	Aluminum Shielding Required* (gm/cm^2)		
	Total (gm/cm^2)	Wall (gm/cm^2)	Net Shielding (gm/cm^2)
3	1.45	0.41	1.04
6	2.5	0.41	2.09
12	12.0	0.41	11.60

*For an active sun exposure dose limit of 100 rad/mission.

Shield Weights. The Two Compartment Polar Orbit Laboratory is described in Section 3.1.2. Tables 3-7 and 3-8 show approximate shield weights for this configuration derived from the shielding given in Table 3-6 for two alternate shielding approaches.

Table 3-7

ADDITIONAL SPACE STATION SHIELD WEIGHTS
FOR 200-N. MILE POLAR ORBIT (QUIET SUN)

Mission Time, (months)	Aluminum Shield Weight (lb)	
	One-Compartment Dependent Laboratory	Two-Compartment Independent Laboratory
3	1520	2320
6	2320	3540
12	3630	5550

NOTE: These shield weights are to be added to the existing structure and are for quiet sun conditions.

Table 3-8

LOCAL PERSONNEL SHIELD WEIGHTS FOR
200-N. MILE POLAR ORBIT

Mission Time (months)	SHIELD WEIGHT REQUIREMENTS* Lb/Helmet		Lb/Tunic		Lb/Bunk		Total For 3 Men (lb)	
	Quiet Sun	Active Sun	Quiet Sun	Active Sun	Quiet Sun	Active Sun	Quiet Sun	Active Sun
3	11.1	11.1	0	0	260	260	282	282
6	17.0	22.2	14.4	18.9	396	520	459	602
12	27.0	126	29.3	137	622	2900	735	3426

*one bunk plus two helmets and two tunics for every three men.

Table 3-7 shows weights for the case when the entire structure is shielded. Table 3-8 shows local body shield weights (See Reference 3.2-9 for a description of local body shielding).

Examination of Tables 3-7 and 3-8 shows that the local body shields are appreciably lighter in weight, due primarily to the reduced area involved. Recommendation of the shielding method should not be based solely on the weight trade-off inasmuch as crew mobility and efficiency may be affected by the suits and helmets. Rather, the method selection should be deferred until test data are available on the effects of personal body shielding.

3.2.2 Space Radiation Shielding - Synchronous Orbit

The space radiation environment and shielding requirements for the synchronous orbit mission are discussed in Sections 3.2.2.1 and 3.2.2.2 respectively.

3.2.2.1 Space Radiation Environment

Galactic Cosmic Rays. The absorbed radiation dose due to the high energy cosmic rays for synchronous altitude conditions (19,380 n. miles and 30 deg inclination) is estimated to be 4.2 rads per year.

Electron Dose During Transit

An analysis of the electron dose received during passage through the geomagnetically trapped particle belts for the Two Compartment Laboratory has been completed. From a transfer perigee altitude of 105 n. miles, the space station is positioned in a 30 deg synchronous orbit 5.2 hours later. The space station altitudes are given in Table 3-9 as a function of time and are schematically shown in Fig. 3-31.

Table 3-9

ALTITUDE - TIME PROFILE FOR TRANSFER TO SYNCHRONOUS ORBIT

Time After Application of Transfer Impulse (hr)	Altitude (n.miles)
0.2	1080
0.5	2900
0.7	4720
0.9	6420
1.12	7940
1.34	9350
1.5	10,500
5.2	19,380

The total absorbed dose due to the trapped electrons is approximately 3 rad. If an RBE of 1 is assumed, as in this study, the dose is then 3 rem. In all cases, this dose is received by an unshielded point dosimeter (such as the unshielded eye) behind the space station wall of approximately 0.4 gm/cm^2 (shown in Fig. 3-30). The results of both transits through the inner belts are summarized in Table 3-10.

Table 3-10

ELECTRON DOSE DURING TRANSIT OF THE RADIATION BELTS

Trajectory	Absorbed Dose (rad)	Absorbed Dose (rem)
Outbound	3	3
Inbound	3	3
Total	6	6

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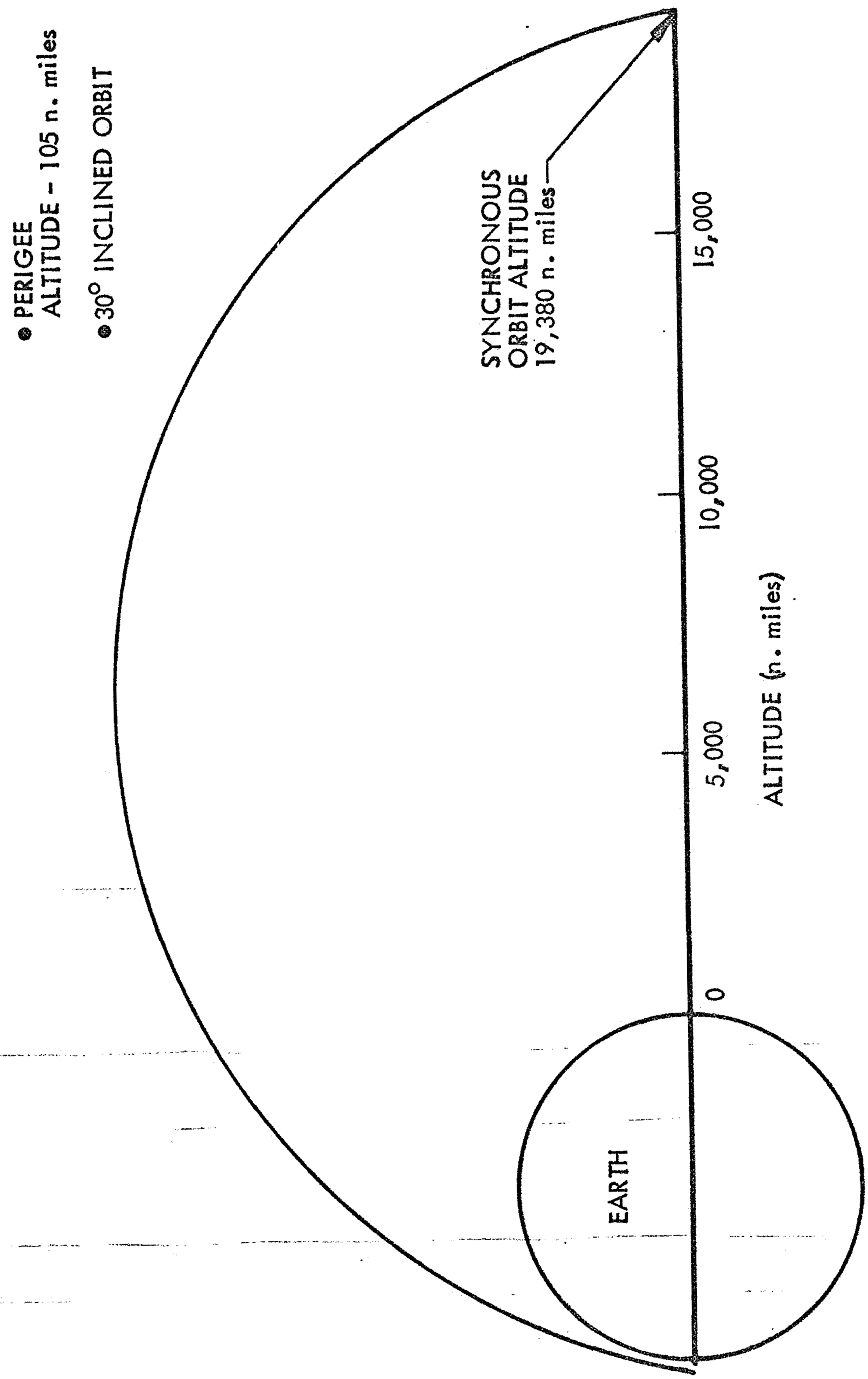

FIG. 3-31 TRAJECTORY PROFILE THROUGH RADIATION BELTS

Table 3.2-9 indicates that the dose received during transit of the radiation belts is relatively small. Recent published data, however, indicates that these results may be optimistic.

Orbital Trapped Electrons. The radiation exposure inside the laboratory due to geomagnetically trapped electrons was estimated for the 30 deg inclination synchronous altitude orbit. The electron data for the time period of interest are assumed to be identical with the data of Frank (Ref. 3.2-2) and are shown in Fig. 3 -32.

This spectrum shows 10^4 electrons/cm^2-sec with energies greater than 2 Mev. In this study, all electrons greater than 2 Mev were assumed to be of that energy since the high energy spectral distribution of electrons greater than 2 Mev is currently unavailable.

Approximately 1.7×10^{12} electrons/cm^2 per day above 0.04 Mev are intercepted in the synchronous orbit. This results in a dose to the eye of approximately 316 rads/day behind the basic laboratory wall structure. This large dose rate is due predominantly to the low energy electrons that have a relatively large ionization effectiveness.

The high dose rate inside the laboratory structure necessitates shielding for missions of any duration at this altitude on the basis of a 27-rad dose limit to the eye. Specific shielding requirements are discussed in Section 3.2.2.2.

Bremsstrahlung. The electron spectrum of Fig. 3-32 is used in this study to calculate bremsstrahlung. The calculation is performed using the method of Green (Reference 3.2-3, and from data of Reference 3.2.-3 and 3.2-4).

The results of this calculation are shown in Fig. 3- 33. This figure shows the synchronous altitude bremsstrahlung dose for electrons stopped in aluminum and attenuated by lead for mission times of 3, 6, and 12 months. The shielding necessary to reduce both the bremsstrahlung doses and other space radiation doses is disucssed further in Section 3.2.2.2.

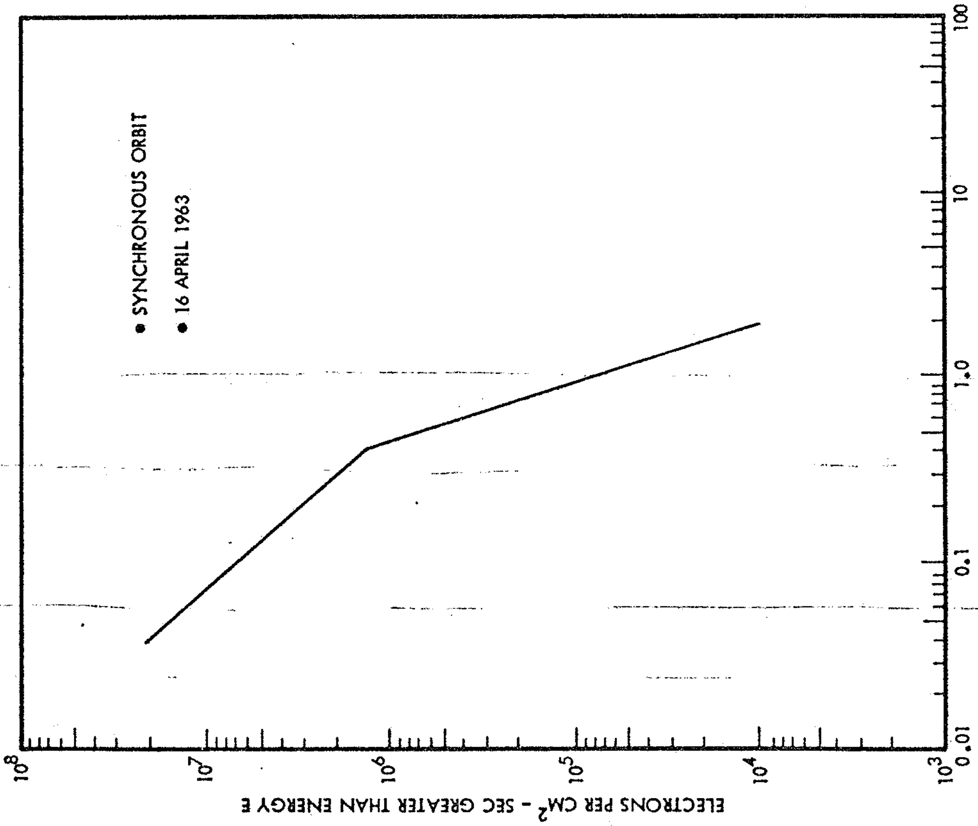

FIGURE 3-32 INTEGRAL ELECTRON SPECTRUM FOR THE OUTER RADIATION BELT (Ref. 3.2-2)

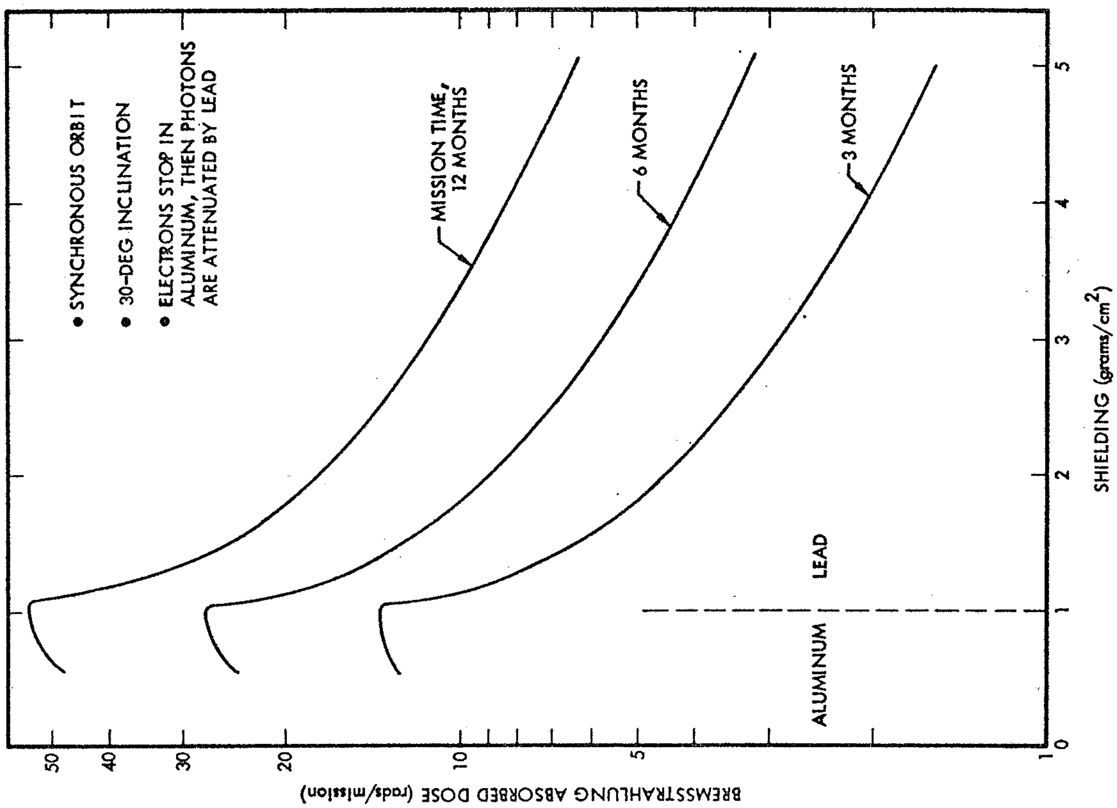

FIGURE 3-33 BREMSSTRAHLUNG ABSORBED DOSE FOR VARIOUS SHIELD THICKNESSES AND MISSION DURATIONS IN A SYNCHRONOUS ORBIT

Trapped Protons. The internal radiation dose due to trapped protons has been calculated for the 30 deg, synchronous orbit altitude. Considerable variance has been noted among the various sources of information for the spatial distribution of protons. For this study, the data of Bane, et al (Ref. 3.2-5) has been selected. The energy spectrum is shown in Fig. 3-34. The data are for October 4, 1960; other sources of information showed fluxes differing by a factor of 10 from these values. This energy spectrum can be represented by the following equations:

$$J = 2 \times 10^{6}\ E^{-5.2}\ \text{protons/cm}^2\text{-sec-sterad-Mev}$$
$$\text{for } 1.02 < E < 2.24 \text{ Mev}$$

and

$$J = 0.71 \times 10^{6}\ E^{-3.9}\ \text{protons/cm}^2\text{-sec-sterad Mev}$$
$$2.24 < E < 7.3 \text{ Mev}$$

Because of the low energy distribution of the outer belt protons, the protection of the wall structure of the laboratory is found to be sufficient for reducing the proton dose to negligible levels.

An investigation of the penetration of the high energy component and its effect on personnel is recommended.

Solar Protons. In this study, the recent NASA solar flare data of Modisette, et al (see Ref. 3.2-7) has been utilized. The integral solar proton flux spectrum is taken to be:

$$F(>E) = G \exp\left[-P(E)/P_o\right]$$

where E = proton energy (Mev)

$F(>E)$ = number of protons having energy greater than E, protons/cm^2.

$P(E)$ = magnetic rigidity*, or momentum per unit charge of a particle, million volts (Mv)

P_o = characteristic regidity (spectrum parameter), in million volts (Mv)

G = a constant, 11.4

*For a more detailed explanation of rigidity, see Ref. 3.2-6.

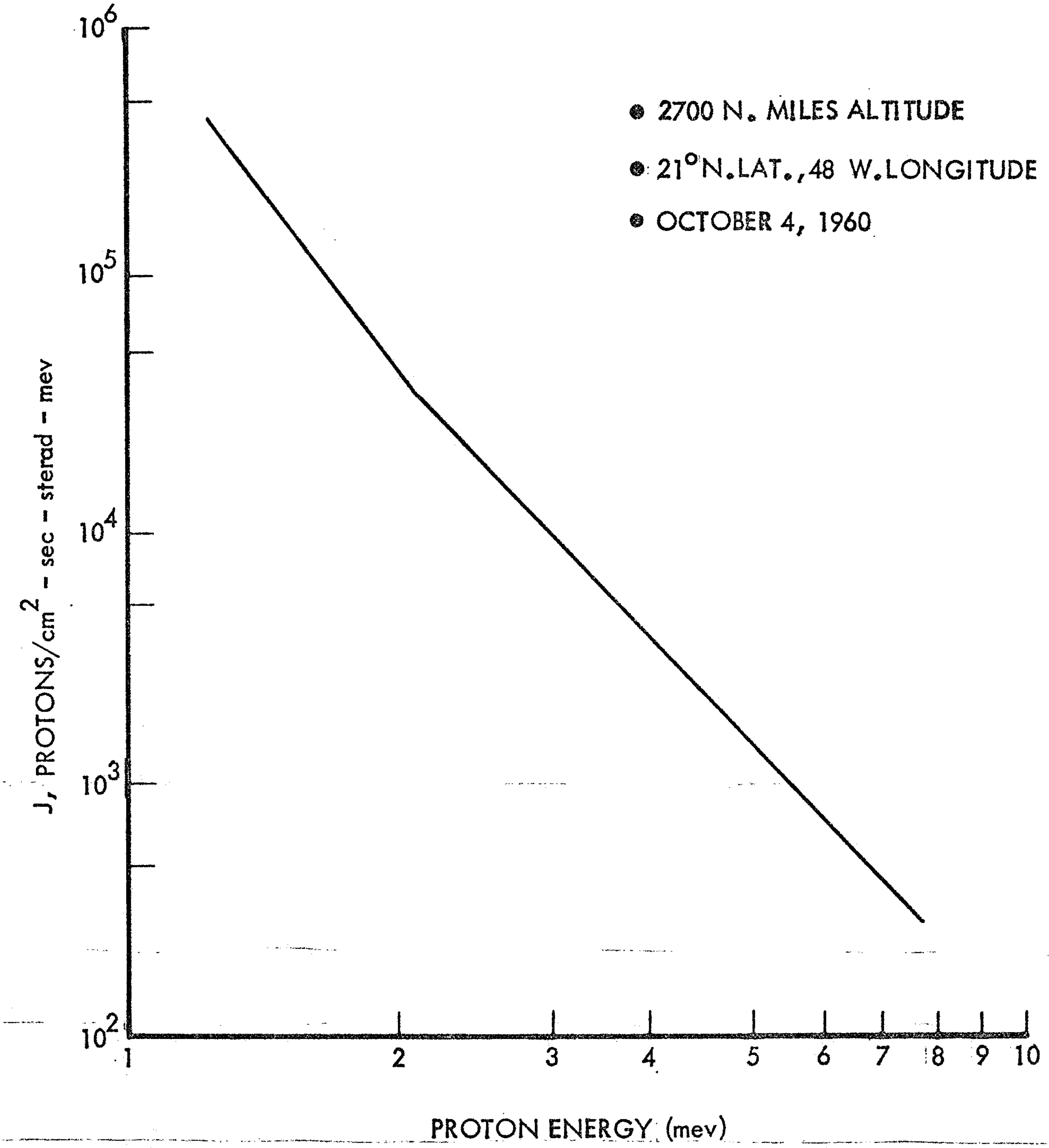

FIG. 3-34 TRAPPED PROTON ENERGY SPECTRUM OF THE OUTER RADIATION BELT (REF. 3.2-5)

In this study P_o is given the value of 97 Mv which corresponds to an average energy spectrum.

The solar proton cutoff rigidity is determined (see Ref. 3.2-10) from:

$$P_c = \frac{2.49 \times 10^{12}}{(6.371 \times 10^3 + h)^2} \left[\frac{2 + \cos^3\lambda - 2\,(1 + \cos^3\lambda)^{\frac{1}{2}}}{\cos^2\lambda} \right]$$

where: P_c = particle cutoff rigidity, Mv

h = altitude, km

λ = geomagnetic latitude, deg

Values of P_c for a 30-deg synchronous orbit and low altitude polar orbit are 150 Mv and 61 Mv, respectively. These correspond to energies of 10 Mev and 10^{-4} Mev, respectively. Since virtually no high energy protons are cut off for either mission, a zero energy cutoff was assumed in this analysis.

The number of solar protons intercepted for various mission times and for various probabilities are taken from Ref. 3.2-7 and shown in Table 3-3. The number of protons intercepted varies from 5.9×10^9 protons/cm^2 for a 12 months mission with a 90 percent probability that no more protons are intercepted, to 1.5×10^{11} protons/cm^2 with a 99.9 percent probability that no more protons are intercepted.

In low altitude orbits, the quoted numbers are reduced by a factor of two as a correction for time spent at low latitudes. The shielding necessary to protect the crew for each of the above solar flare conditions is shown in Table 3-11. This shielding is required to limit solar flare doses to the 100 rad/mission emergency exposure dose to the eye.

Table 3-11

TOTAL SOLAR FLARE SHIELDING REQUIRED AT
SYNCHRONOUS ALTITUDE FOR VARIOUS MISSION TIMES

Probability of Not Exceeding 100 Rads/Mission	Mission Time, Months		
	3	6	12
.90	Aluminum 1.5 gm/cm^2	Aluminum 5.5 gm/cm^2	Aluminum 18 gm/cm^2

Solar Alpha Particles. In this study, the dose due to high energy solar alpha particles is assumed to be in a ratio of 1/2.33 to the dose from solar protons under all conditions. Alpha particle doses are included in the results given in Table 3-11.

3.2.2.2 Shield Requirements - Synchronous Altitude

Shield Thickness. Electrons and electron bremsstrahlung have been shown to contribute significantly to the dose in the synchronous orbit. In addition, space radiation doses are received during the Hohmann transfer and from cosmic rays. The various space photons and particles are attenuated differently in the several shielding materials in a complex manner. For example, aluminum is an efficient shield for electrons, while lead is efficient for bremsstrahlung.

Table 3-12 shows the results for the synchronous altitude environment for two solar conditions, quiet and active sun. The left side of this table shows the aluminum and lead requirements necessary to maintain 3, 6, and 12-months missions with a total mission absorbed dose of 27 rads/mission to the eyes during quiet sun conditions. It is important that the aluminum shielding be external to the lead. These requirements consider the effects of trapped radiation, bremsstrahlung, and cosmic rays. Solar proton event effects are not included in the quiet sun results.

Table 3-12

TOTAL SHIELDING REQUIRED FOR
30-DEG INCLINATION, SYNCHRONOUS ORBIT

Mission Time (months)	Shielding Required (gm/cm^2)					
	Quiet Sun			Active Sun Conditions		
	Aluminum	Lead	Total	Aluminum	Lead	Total
3	0.59	0	0.59	1.09	0	1.09
6	0.59	0.1	0.69	5.09	0.1	5.19
12	0.59	1	1.59	17.6	1	18.6

NOTE: The above shielding is required in addition to the space station wall structure. The solar flare particle dose is equal to or less than 100 rad per mission.

The right side of this table shows the aluminum and lead shielding necessary to maintain 3, 6, and 12 months missions during active solar conditions. In this case, 27 rad/mission absorbed dose to the eye is allowed from continuous radiation (i.e. trapped radiation, cosmic rays) and 100 rad/mission are allowed as an emergency exposure solar flare dose. In general, during active solar conditions, the shielding requirements are greater than those during quiet conditions. Consequently, the shielding shown in Table 3-12 is added, where possible, to a storm cellar in order to minimize weight.

Shield Weights. Approximate shield weights for the requirements given in the previous section, are shown in Tables 3-13 and 3-14 for one and two compartment configurations in a 30-deg inclination synchronous orbit. The single compartment is assumed to be a cylinder 15.25 ft in diameter and 8.16 ft in length; the double compartment is the same diameter but 15.64 ft in length.

Here again, local body shielding produces a substantial weight saving; however, degradation of crew performance can also be expected when using the personal body shielding for long time periods. A compromise recommendation is therefore made that the complete module be shielded for quiet sun conditions and that personal body shielding be provided for active solar periods only. Figure 3-35 illustrates the combination of

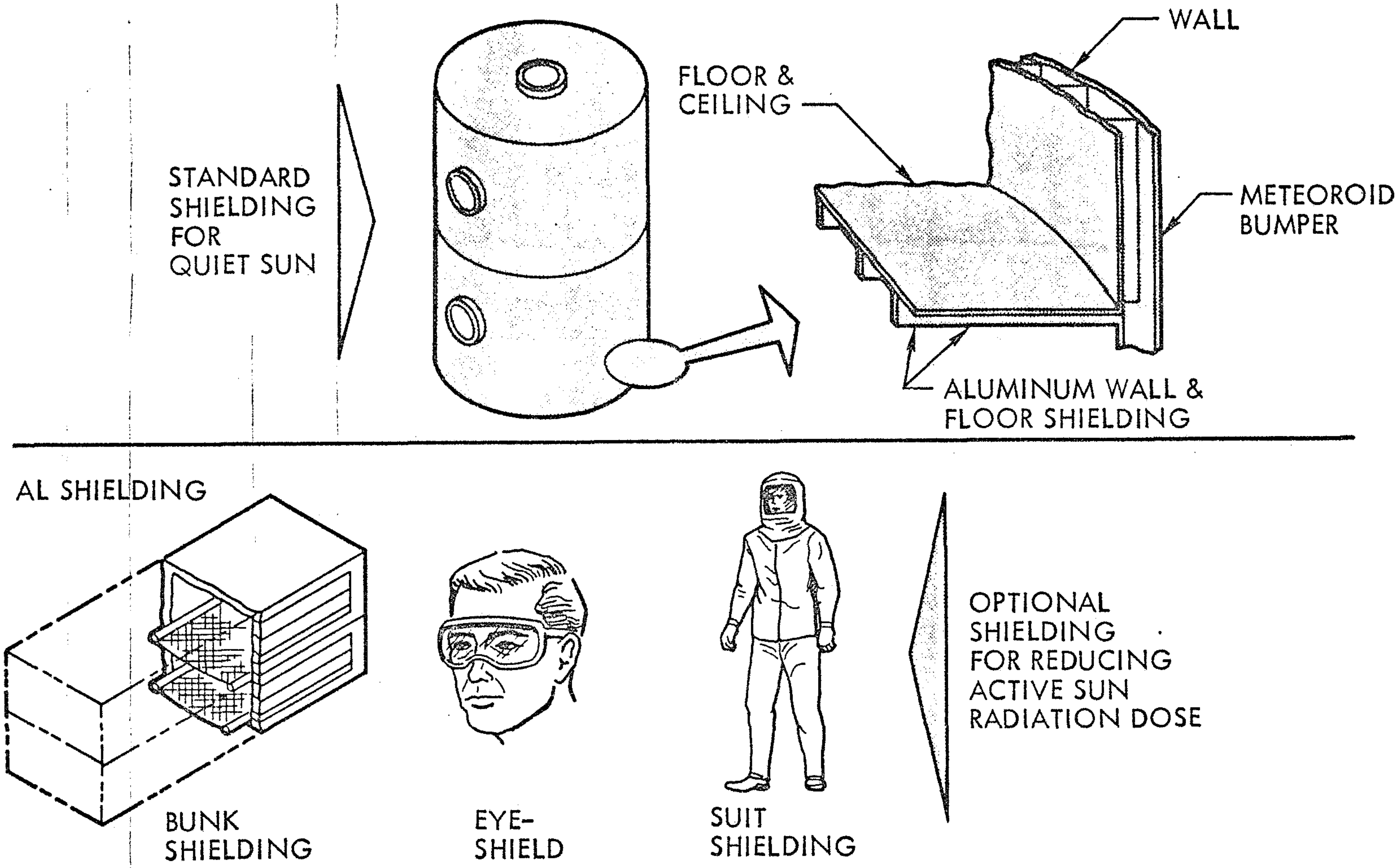

FIG. 3-35 RADIATION SHIELDING METHODS

the two shielding methods. These tables indicate also the weight penalty involved if crew time in orbit must be extended beyond the postulated three-month period.

Table 3 -13

TOTAL STRUCTURE SHIELDING WEIGHTS
FOR 30-DEG INCLINATION, SYNCHRONOUS ORBIT

Mission Time, (months)	Space Radiation Shield Weight (lb)			
	One Compartment Dependent Laboratory		Two Compartment Independent Laboratory	
	Quiet Sun	Active Sun	Quiet Sun	Active Sun
3	892	1645	1315	2430
6	1042	7830	1540	11,580
12	2400	28,100	3540	41,400

Table 3-14

LOCAL BODY SHIELDING WEIGHTS FOR
30-DEG INCLINATION, SYNCHRONOUS ORBIT

Mission Time, (months)	Shielding Weight Requirements*					
	lb/Helmet		lb/Tunic		lb/Bunk	
	Quiet Sun	Active Sun	Quiet Sun	Active Sun	Quiet Sun	Active Sun
3	6.3	11.7	20.4	37.7	148	273
6	7.2	54.2	31.0	233	172	1295
12	17.0	199	137.0	1604	397	4640

* Assumes no structure shielding. Also, one bunk plus two helmets and two tunics are assumed for each three men.

Further research is needed in the areas indicated below:

- Recent data in the literature indicates that the biological doses received during transit through the radiation belts may be higher than those shown here. Considerable research is required to resolve this matter.
- The attentuation and scattering effects due to the transmission of energetic electrons and protons through the spacecraft wall structures have been estimated. Of special interest, are the

high energy particles that are present and the magnitude of their contribution to the dose. Further work is required to define the spectra of the high energy components that are present at the altitudes of interest.

- The effects of shielding by internal equipment have been neglected in this report because of the multiplicity of interior arrangements. Since other studies have shown that these effects can be important, further work in this area is recommended.

REFERENCES-Section 3.2

3.2-1 Freden, S. C. and White, R. S., "Protons in the Earth's Magnetic Field", Phys. Rev. Letters No. 1, 9, 1959.

3.2-2 Frank, Louis Albert, "A Survey of Electrons Beyond 5 R_e with Explorer XIV", SUI 64-13 June 1964.

3.2-3 Artificial Electron Belt Dose Rates by W. B. Green 5-10-63 (Unpublished Lockheed-California Co. data)

3.2-4 Evans, Robley D., The Atomic Nucleus - McGraw-Hill, 1955.

3.2-5 Bane, S. J., J. P. Connor, et al, Protons in the Outer Zone of the Radiation Belt, Jour. of Geophys. Research Vol. 68, No. 1, 55-63, 1963.

3.2-6 Winckler, John R., "The Production and Propagation of Energetic Particles from the Sun" in Space Science, John Wiley and Sons, Inc. 1963.

3.2-7 Modisette, Jerry L., Terence M. Vinson, and Alva C. Hardy, "Model Solar Proton Environments for Manned Spacecraft Design". (To be published)

3.2-8 Communication from W. N. Hess, Goddard Space Flight Center to Users of the E8 Grid, dated Oct. 20, 1964.

3.2-9 LR 17502, Rotating Manned Orbital Space Station, 20 Feb. 1964.

3.2-10 U. S. Government, Memorandum dated Dec. 16, 1964 to ET4, Space Station Study Office from ET322, Radiation Analysis Section.

3.3 STRUCTURAL DESIGN

The basic modular unit of the Modular Multipurpose Space Station is structurally a large pressure cylinder with flat ends. Hatches are located at the center of each flat end and two diametrically opposite hatches are located in the cylindrical side walls. The hatches incorporate docking rings for accommodating logistic spacecraft or other hatch attachments. The two hatches in the flat ends of the module are also designed as hoist points for ground handling.

The cylindrical walls incorporate an inner pressure barrier with integral stiffeners on the outside. Standoff fiberglass clips are attached to the external stiffeners for the support of an outer meteoroid bumper, which is non-structural.

Pressure bulkheads, which form the floor and ceiling of the module, incorporate a system of beams with ties at the central hatches, to support the differential pressure load. The beams are designed with fiberglass shear webs to reduce the conduction of heat. External floors and ceilings are protected by a meteoroid bumper.

Thermal insulation consisting of aluminized mylar sheets is contained within the module walls between the pressure barrier and the meteoroid bumper.

The pressure shell is entirely of welded construction to reduce leakage. The basic shell material is 2219-T87 aluminum alloy, which was chosen for its excellent weldability and crack resistant properties. Additional thickness is provided locally at the welds so that a uniform strength level is maintained without post-weld heat treatment.

The following analysis presents critical load criteria and stress analysis of the primary structure.

3.3.1 Loads

Primary Spaceframe Structure

A factor of safety of 1.50 is used for all conditions. The stress in any element of the structure when subjected to ultimate load must not exceed the allowable stress of the material.

Transient Loads

To account for dynamic effects, the exit flight loads include a factor of 1.20 and the pre-launch and launch loads include a factor of 1.15.

Thermal Stresses

The ultimate factor of safety for thermal stresses is to be 1.0 when combined with other stresses.

Pressure Vessels

Pressure vessels are to be designed to the following factors:

(a) Cabin and pressurized compartments, pressure acting alone:

Limit pressure = 1.33 x maximum operating pressure.
Ultimate pressure = 2.0 x maximum operating pressure.

(b) Cabin and pressurized compartments, pressure combined with flight loads:

Limit pressure = maximum operating pressure.
Ultimate pressure = 1.5 x maximum operating pressure.

Pre-Launch and Ground Handling

The pre-launch phase is concluded with the removal of the gantry. Loads encountered during this phase are:

(a) Hoisting

A vertical limit load factor of 2.0 shall be applied within a cone angle of 20 deg from the vertical through the pick-up points.

(b) Wind Environment

Ground wind data to be used in the structural analysis for the design of the vehicle are presented in Reference 1. These data present steady state and peak winds in fps as a function of altitude to 500 feet for 95 and 99 percent probability of occurrence with respect to the worst wind month.

During this pre-launch phase, the vehicle must be capable of sustaining the 99 percent probability ground wind.

(c) Jig Support

The floor docking rings constitute jig support points for the loaded module. The limit load factor = 2.0.

Launch

The launch phase is defined as the time from removal of the gantry until the pitch-over to trajectory flight. After the gantry is removed, the vehicle must be capable of sustaining the 95 percent probability wind defined in Ref. 3.3-1.

Figure 3-36 presents the bending moment on the modules when mounted on the Saturn IB in a maximum wind shear condition (Ref. 3.3-2).

α = angle of attack, degrees

q = dynamic pressure, pounds per square foot

n_x = axial load factor

Pressure Differential

The design maximum operating pressure for a modular unit of the one, two, and six compartment modular space stations is to be 7.0 psi.

Docking

Relative Axial Velocity = 2 ft per sec.

Relative Lateral Velocity = 1 ft per sec.

Relative Angular Velocity = 1 deg per sec.

Lateral Misalignment = 1 ft

Angular Misalignment = 10 deg

Apollo Orbit Circularization Thrust

Injection of the module into orbit by the Service Module engine produces a thrust load and a bending moment when the engine is fully gimbaled. These loads are applied directly through the docking hatch structure.

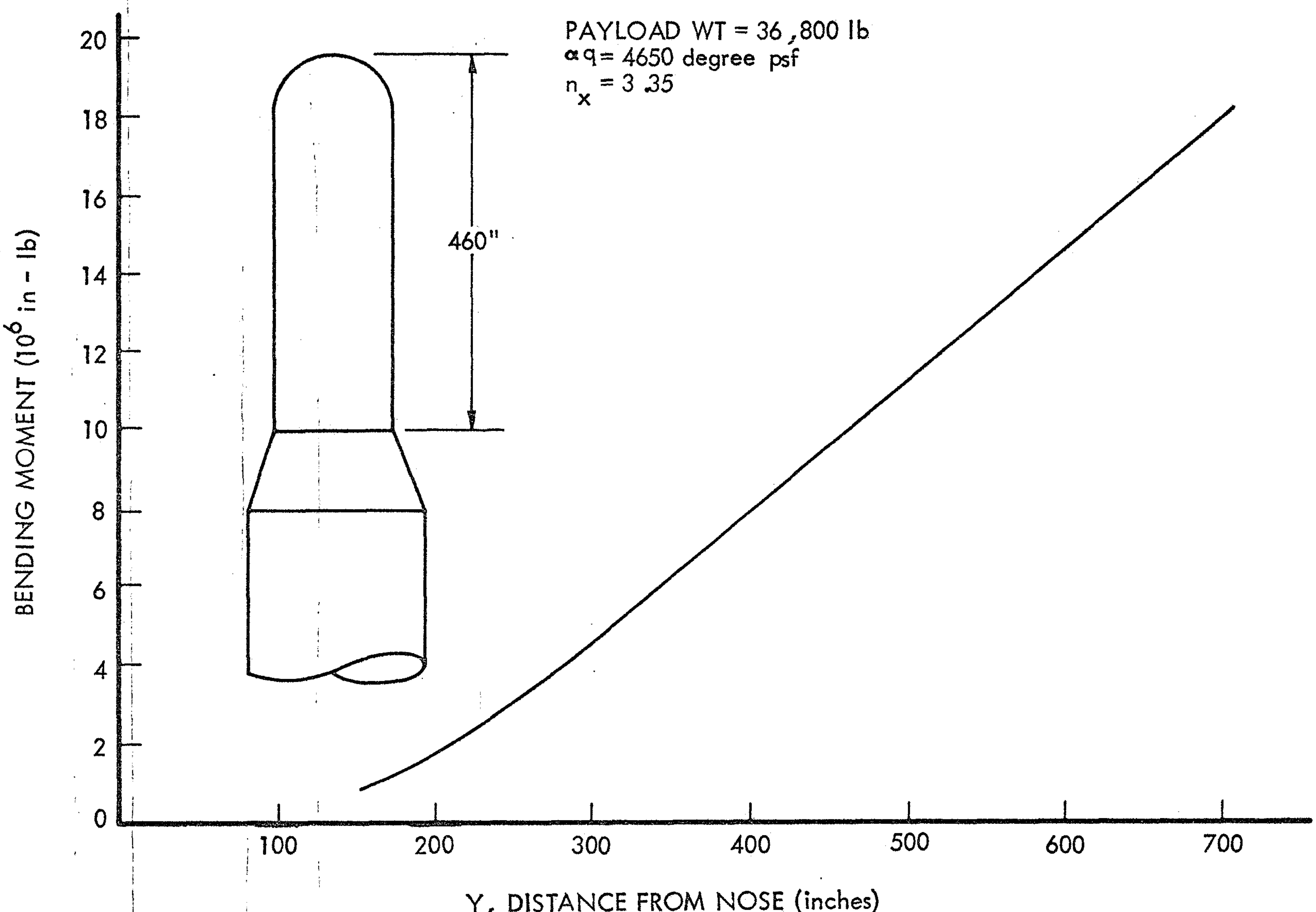

FIG. 3-36 VARIATION OF BENDING LOAD DUE TO WIND SHEAR LOADING

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Engine thrust = 21,900 lb

Gimbal angle = 8 deg

Command module docked with space station.

Meteoroid Protection

The meteoroid environment criteria are stated in the NASA document EC-1 (Ref. 3.3-3) and amended by the original contract Statement of Work. Meteoroid protection for all configurations is to be based on a 0.99 probability of no more than one penetration per worst month on the Operational Space Station.

Fail-Safe Policy

The fail-safe policy, to obtain an acceptable length of crack without rapid propagation in the pressure shell, is as follows:

> The maximum operating hoop tension stress shall not exceed one-half of the ultimate allowable material tensile stress. At shell cutouts, the stress shall not exceed one-fourth of the ultimate allowable tensile stress.

3.3.2 Stress Analysis

In the following stress analysis, calculations are presented that substantiate the adequacy of the design that is described in Section 3.1 and in the drawings, for the loading conditions and factors of safety described in Section 3.3.1, Loads. The design is accomplished such that objectionable permanent set will not occur at limit load conditions and failure will not occur at less than design ultimate loads.

3.3.2.1 Meteoroid Protection

The penetration formulas and structural factors are shown below:

Penetrating flux, $$N = \frac{n}{S_F(KA_S + FA_p)T}$$

where:

n = The total number of penetrations with a given probability

S_F = Earth shielding factor

K = Ratio of the rate of flux of sporadic meteoroids during the time T to yearly average.

F = Ratio of the rate of flux of showers to the sporadic rate

A_S = Vehicle surface area (ft^2)

A_p = Vehicle projected area (ft^2)

T = Mission time (days)

For a .99 probability of not more than 1 penetration each 30 days for the Operational Modular Multipurpose Space Station configuration,

*$n = .15$	$S_F = .696$	$K = 1.7$
$F = 1.0$	$A_S = 20,500\ ft^2$	$A_p = 4,850\ ft^2$
$T = 30$ days	$N = 1.81 \times 10^{-7}$	

The size of meteoroid against which protection is required is taken from a curve of yearly average sporadic flux based on the 1963A Whipple distribution and represented by the equation:

$$\text{Log } N = -1.34 \log m - 10.423, \text{ from which:}$$

$$m = .00178 \text{ gm. (meteoroid mass)}$$

$$* \quad P_x = \sum_{r=o}^{r=x} \frac{n^r}{r!} e^{-n}$$

where:

P_x is the probability of not exceeding x penetrations in accordance with Poisson's Distribution.

For x = 1 penetration, and P = .99 probability,

$$.99 = e^{-n} + ne^{-n}$$

$$\therefore \ n = .15$$

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To prevent penetration of a single sheet;

$$t = 148\ K_1 \left(\frac{m}{E_t \rho_t} \right)^{1/3} \quad \text{,Summers Equation}$$

where:

K_1 = 1.5 (thin sheet factor)

E_t = Modulus of elasticity of sheet (psi)

ρ_t = Density of sheet (lb/in^3)

For aluminum, the single sheet requirement is

$$t = 2.18\ m^{1/3} = .264 \text{ in.}$$

For two sheets spaced 2 in. apart, the structural factor K_2 = .20

$$t_1 + t_2 = K_2 t = .20 \times .264 = .053 \text{ in.}$$

t_1 = bumper sheet = .016 in. minimum

t_2 = inside sheet = .037 in.

The 0.037-in. thickness is adopted for the integrally machined pressure skin, but 0.020-in. gage is recommended for the meteoroid bumper because of its handling qualities.

3.3.2.2 Cylindrical Shell Pressure Requirements

Ultimate pressure P = 2 x 7.0 = 14.0 psi

Allowable ultimate hoop tension stress for 2219 T87:

F_{tu} = 62,000 psi

Required pressure skin thickness:

$$t = \frac{PR}{F_{tu}}$$

Module radius R = 89.5 in.

$$t = \frac{14 \times 89.5}{62,000} = .020 \text{ in.}$$

Actual skin thickness = .037 in.

$$\text{Margin of Safety, M.S.} = \frac{.037}{.020} - 1 = .85$$

3.3.2.3 Compression Analysis of the Module Skin

Figure 3-36 shows the variation of shell bending with distance from the nose of the vehicle. The shear, moment and axial loads at the critical station y = 460 in. are as follows:

P (axial) = 110,000 lb limit
S (shear) = 32,800 lb limit
M (moment) = 10×10^6 lb-in. limit

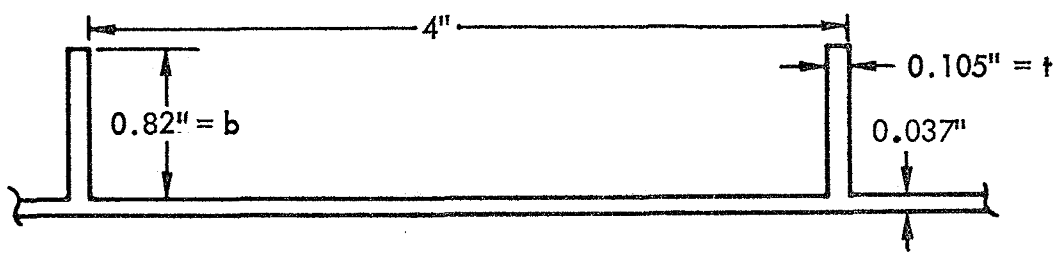
the ultimate shell loads at station 460 are:

$$p = \frac{P}{2\pi R} + \frac{M}{\pi R^2} \quad \text{where } R = 89.5 \text{ in.}$$

$$= \frac{110{,}000 \times 1.5}{2 \times 89.5\pi} + \frac{10 \times 1.5 \times 10^6}{(89.5)^2\pi}$$

$$= 293 + 596 = 889 \text{ lb/in}$$

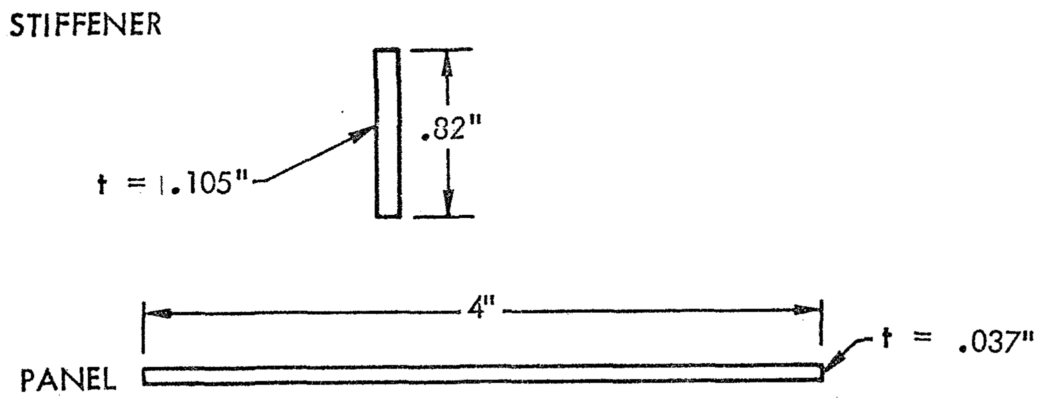
Panel Stability (Crippling)



The stiffener size for integrally stiffened skin with stiffeners spaced at 4.0 in. and skin thickness of .037 in. is shown in the accompanying sketches. The crippling stress allowable for this section is computed from Lockheed Stress Memo SM 126 (Ref. 3.3.-4) as follows:

$$\text{Stiffener ratio, } b/t = \frac{\text{element width}}{\text{element thickness}} = \frac{0.82}{0.105} = 7.8$$

For one edge free, the crippling stress, F_c = 30,000 psi.



Panel ratio, $\frac{b}{t} = \frac{4}{.037} = 108$

For no edge free, $F_c = 10{,}000$ psi

$$F_c = \frac{\Sigma F_C A}{\Sigma A} = \frac{10{,}000\ (.148) + 30{,}000\ (.086)}{.234} = 17{,}300 \text{ psi}$$

The ultimate maximum compression load shown previously is 889 lb/in.

Shell area per inch $= \frac{.234}{4} = .0585$

$$F_c = 889/.0585 = 15{,}200 \text{ psi}$$

Ultimate margin of safety in crippling $= \frac{17{,}300}{15{,}200} - 1 = 0.14$

Panel Stability (Column Buckling)

As a part of the assessment of panel stability, column buckling was investigated; results of this analysis follow:

I = Unit moment of inertia of skin and stiffeners $= .00402 \text{ in.}^4/\text{in.}$

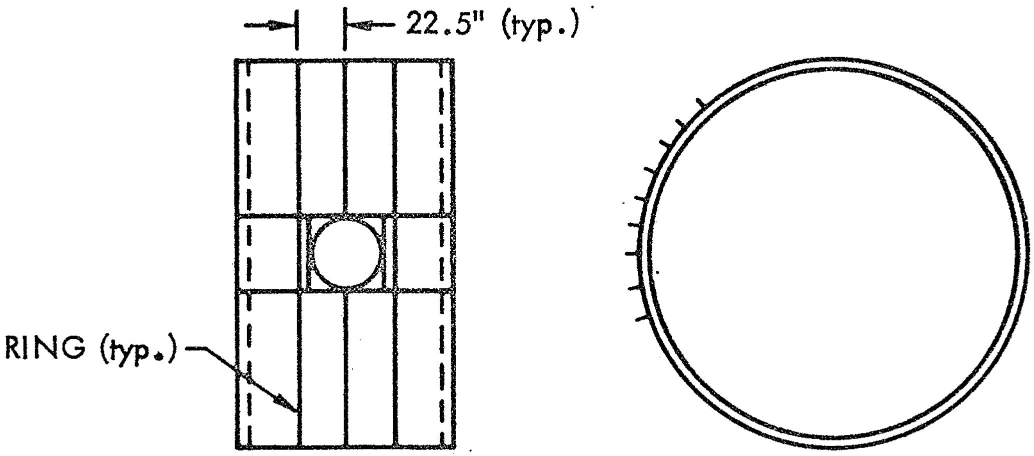
ρ = Radius of Gyration $= \sqrt{\frac{I}{A}} = \sqrt{\frac{.00402}{.0585}} = .261$ in.

Ring Spacing = 22.5 In. (Three rings required, see following sketch)

$L'/\rho = \frac{22.5}{.261\sqrt{1.5}} = 70.5$; Column end fixity, $C = 1.5$.

$F_{co} = 20{,}000$ psi (Ref. 3.3-4, SM83b)

Ultimate margin of safety in column buckling $= \frac{20{,}000}{15{,}000} - 1 = +0.33$.



General Stability, Shell

This design criterion establishes the cross-sectional area of the rings. Ref. 5, page 73, gives:

$$E_F I_F \geqslant \frac{C_f M D^2}{L}, \text{ where:}$$

E_F = Young's modulus, frame (ring)

I_F = Moment of inertia of frame cross-section.

C_f = A dimensionless coefficient (1.25×10^{-4})*

M = Applied moment

D = Shell diameter

L = Frame spacing.

Accounting for axial loading, the equivalent applied moment is:

$$M = p\pi R^2 = 826 \times \pi \times 89.5^2 = 20.4 \times 10^6 \text{ in.lb ult.}$$

$$E_F I_F \geqslant \frac{1.25 \times 10^{-4} \times 20.4 \times 10^6 \times 179^2}{22.5} = 3.62 \times 10^6 \text{ lb-in.}^2$$

* Value of C_f doubled on the basis of Lockheed Test Results. (Ref. LR 15764)

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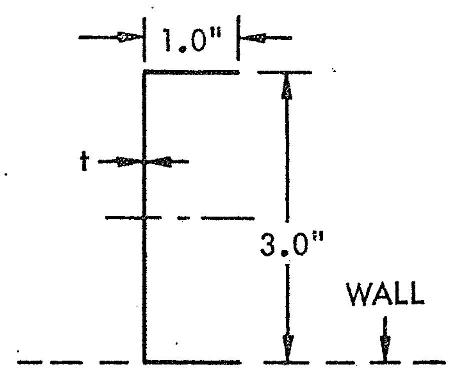
$E_F = 10^7$ psi; $I_F = .362$ In.^{4}

Assume 3.0-in. deep rings, (see sketch)



$$I_F = 2t \times 1.50^2 + \frac{3.0^3 t}{12}$$

$$= 4.50t + 2.25t = 6.75t$$

$$t = \frac{.362}{6.75} = .0535 \text{ in.}$$

Use .060 In. 2219-T87 aluminum alloy.

Ring area = 5 x .060 = .30 in.^{2} each.

3.3.2.4 Docking Support Structure on Module Shell

Docking Loads. Assume the two body impact conditions are as follows:

Apollo command and service modules = 15,000 lb., weight

Two-compartment station + spent S-IVB stage= 37,000 lb , weight

$$\Delta V = 2 \text{ fps}$$

$$S = 7 \text{ in. stroke (deflection)} = 0.582 \text{ ft.}$$

Impact energy = resisting energy

$$\frac{MV^2}{2} = FS, \text{ where } FS = \text{docking force x stroke}$$

$$\frac{WV^2}{2gS} = F$$

Equivalent docking weight,

$$W = \frac{W_1 W_2}{W_1 + W_2}, \text{ where}$$

W_1 = 15,000 lb (Apollo command and service modules)

W_2 = 37,000 lb (Two-compartment station plus spent SIV stage)

$$W = \frac{15{,}000 \times 37{,}000}{52{,}000} = 10{,}700 \text{ lb}$$

$$F = \frac{WV^2}{2gS} = \frac{10{,}700 \times 4}{2 \times 32.2 \times .582} = 1{,}145 \text{ lb}$$

The peak load can be twice the average load, hence

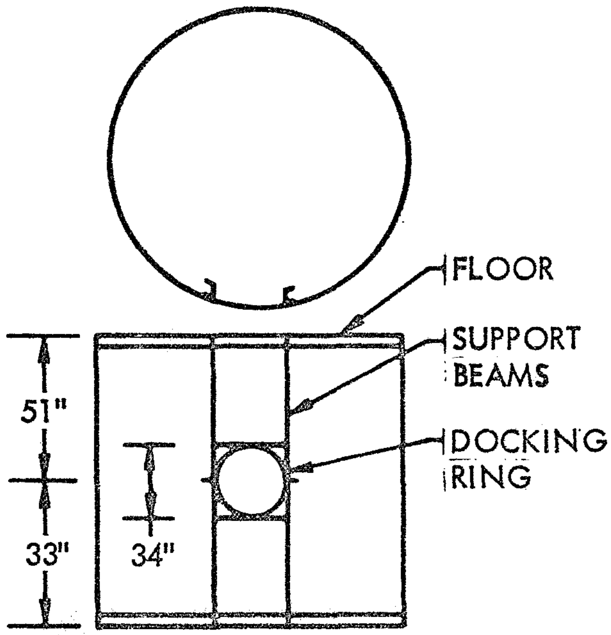
Ultimate docking load $= 1{,}145 \times 2 \times 1.5 = 3{,}430$ lb

Use F $=$ 4,000 lb ultimate for design.

The docking ring is supported by beams spanning the adjacent floors, as shown in these sketches.

Ultimate dock load = 4000 lb.

Assume the support beams react the docking load, i.e., there is no allowance for pressure stiffening.

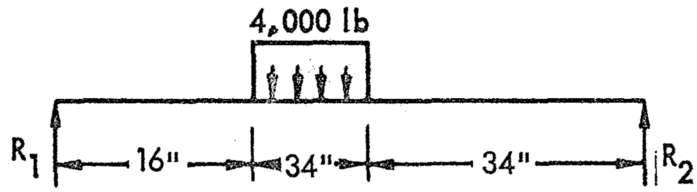


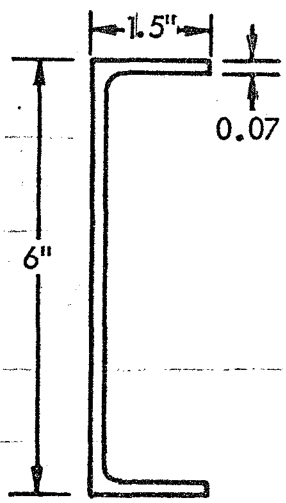
$$\text{Max } R_1 = 4000 \times \frac{51}{84} = 2430 \text{ lb}$$

$$\text{Max } R_2 = 4000 \times \frac{33}{84} = 1570 \text{ lb}$$

An eccentric docking load could be on one edge of the ring such that one support gets most of the load; it is therefore assumed that one support may carry two thirds of the total docking load.

Note: Figures not to scale.





The maximum bending on one support is

$$M = (34R_2)\frac{2}{3} = \frac{34 \times 1570 \times 2}{3} = 35{,}600 \text{ lb-in. ultimate}$$

$$I = .105 \times 2.96^2 \times 2 + \frac{5.86^3 \times .07}{12}$$

$$= 1.84 + 1.17 = 3.01 \text{ in.}^4$$

$$f_b = \frac{35{,}600 \times 3}{3.01} = 35{,}400 \text{ psi}$$

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Allowable flange stress for 2219-T87 aluminum alloy

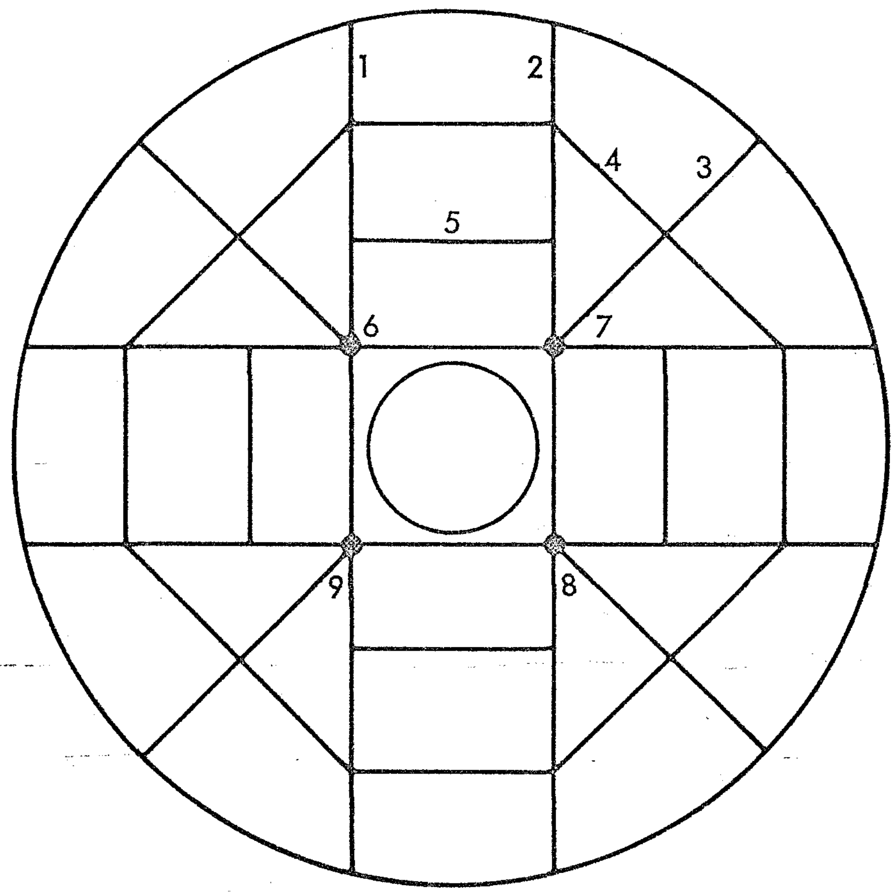
$$F_{tu} = 62{,}000 \text{ psi}$$

$$\text{Tension Flange margin of safety} = \frac{62{,}000}{35{,}400} - 1 = .75$$

The compression flange is not critical because it is supported by shell skin.

3.3.2.5 Beam-Supported Floor

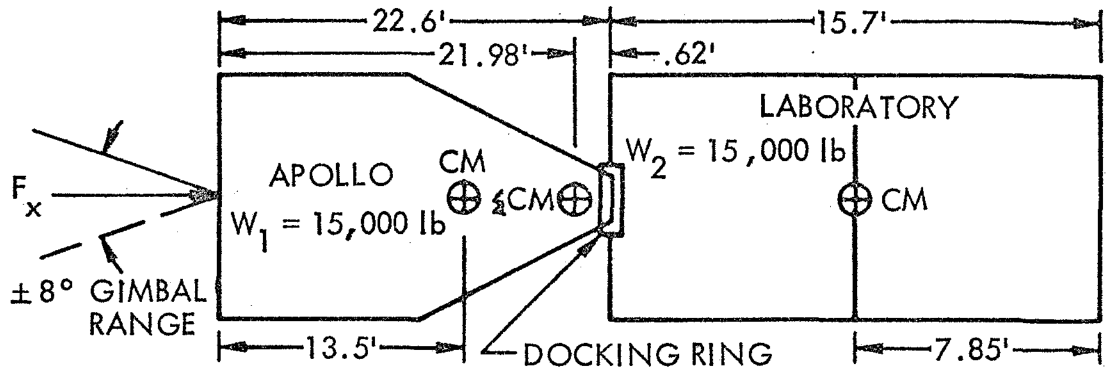
The main support beam locations are shown below.



The beams are pin-supported around the periphery of the floor and continuous at other points. One set of beam flanges and the floor surface are integrally machined from a 1-1/4-inch thick aluminum plate.

Posts at points 6, 7, 8, and 9 constitute structural ties between the floor and the ceiling. These posts transmit pressure, docking and handling loads between the integral beam floors. Each floor beam carries the total pressure load in the area half-way to the adjacent beam.

Loads on Docking Ring Due to Apollo Injection Thrust Condition



In reference to the above diagram of a docked configuration:

$$\text{Acceleration, } a = \frac{F_x g}{W_1 + W_2}, \quad \text{where } F_x = 21{,}900 \text{ lb}$$

$$\text{Docking ring load, } P = \frac{W_2 a}{g} = \frac{W_2 F_x}{W_1 + W_2}$$

$$P_{limit} = \frac{15{,}000 \times 21{,}900}{30{,}000} = 10{,}950 \text{ lb}$$

$$P_{ult.} = 1.5 \times 10{,}950 = 17{,}400 \text{ lb}$$

For an 8-deg engine gimbal

$$F_x = 21{,}900 \cos 8 \text{ deg} = 21{,}600 \text{ lb}$$

$$F_y = F_z = 21{,}900 \sin 8 \text{ deg} = 3{,}050 \text{ lb}$$

Data	Apollo	Laboratory	Combined
Weight (lb)	15,000	15,000	30,000
Mass (slugs)	466	466	932
I_p (slug-ft^2)	23,000	20,000	109,100

$$\text{Distance to combined center of mass, } d = \frac{15{,}000 \times 13.5 + 15{,}000 \times 30.45}{30{,}000}$$

$$= 21.98 \text{ ft.}$$

Combined I_p about CM = 43,000 + 466 $(8.48^2 + 8.47^2)$ = 109,000 slug-ft^2

$$\text{Angular acceleration} = \alpha = \frac{3050 \times 21.98}{109,100}$$

$$\alpha = .614 \text{ rad/sec}^2$$

At the laboratory mass center, the tangential acceleration resulting from the lateral component of thrust is

$$a_z = r\alpha = 8.47 \times .614 = 5.20 \text{ ft/sec}^2$$

The linear acceleration due to this lateral thrust component is

$$a_z = \frac{-3050}{932} = -3.28 \text{ ft/sec}^2$$

The net linear acceleration of the mass center = a_n 5.20 - 3.28

= 1.92 ft/sec^2

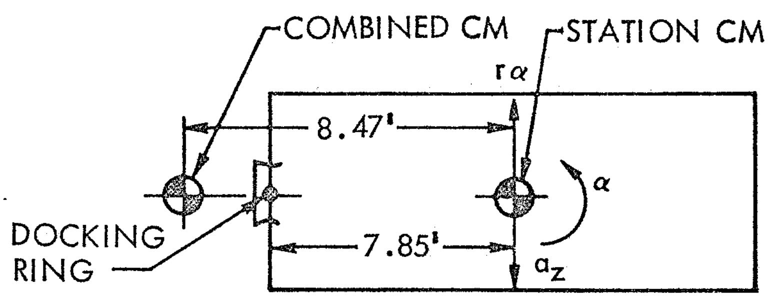
Forces on docking ring

The moment of the forces about the docking ring shown here are:

$$M_{limit} = (m_\ell a_n)d + I_{p_\ell}\alpha$$

$$= 466 \times 1.92 \times 7.85 + 20,000 \times 0.614$$

$$= 19,310 \text{ lb-ft}$$



LABORATORY FREE BODY DIAGRAM

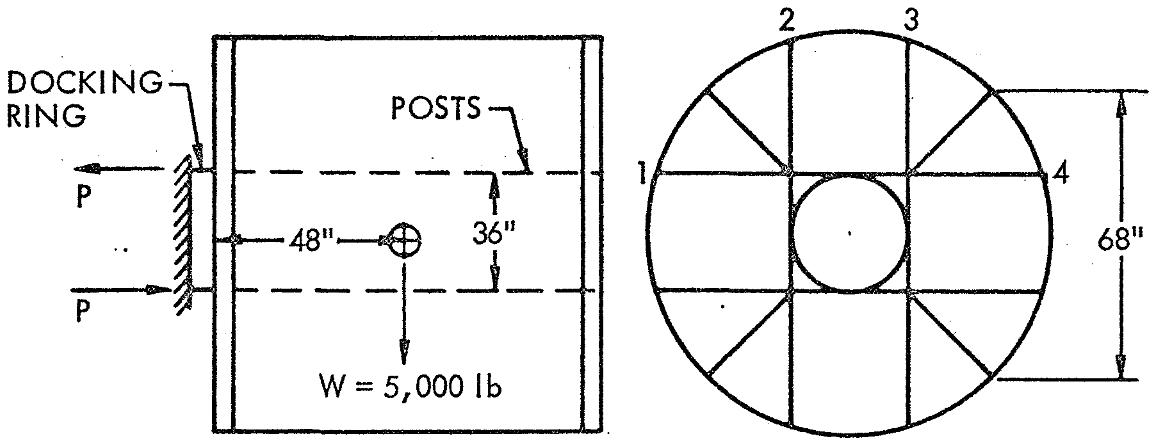
$$M_{ult.} = 19,310 \times 12 \times 1.5 = 348,000 \text{ lb-in.}$$

Loads on Docking Ring Due to Ground Handling Conditions

The loaded module is supported by a jig which attaches to the docking ring. The critical condition for the beams is shown in the following sketch.

The ultimate load factor is 3.0.

$$P_{ult.} = \frac{5000 \times 48 \times 3}{36} = 20,000 \text{ lb}$$



The four floor support posts distribute some of the load P to each floor. A relative deflection analysis shows that 45 percent of the load is distributed to the opposite floor by the posts and 52 percent to the floor adjacent to the holding fixture. It is assumed that the couple forces, P, will be reacted by the beams at points 1, 2, 3 and 4 at an average distance of 68 in. as shown.

The reaction at each of the four points is:

$$R = \frac{20{,}000 \times 36 \times .52}{4 \times 68} = 1{,}380 \text{ lb}$$

and the floor beam bending moment (see below) at each post is:

$$M = 70 \times 1{,}380 = 96{,}500 \text{ lb-in.}$$

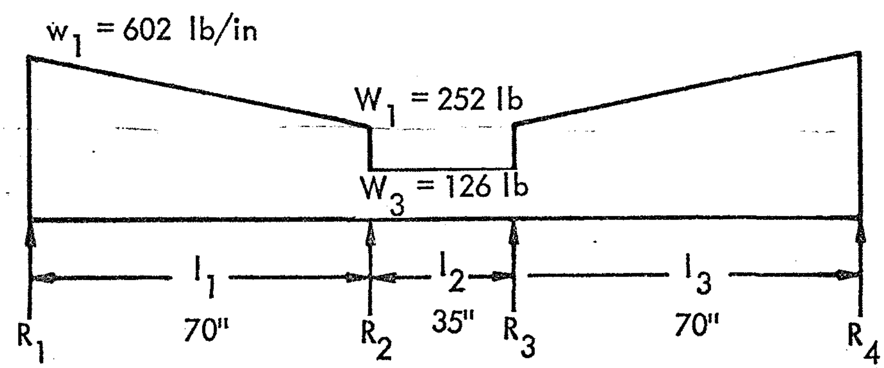
At a point 35 in. from the end of each beam, the bending moment is:

$$M = 35 \times 1{,}380 = 48{,}200 \text{ lb-in.}$$

<u>Uniform Floor Pressure Loading Conditions</u>

The floor beams are designated by number as shown.
The pressure = 2.0 x 7.0 = 14 psi ultimate.

<u>Floor Beam No. 1</u>



From continuous beam theory

$$210\ M_2 + 35\ M_3 = \frac{252 \times 70^3}{4} + \frac{7 \times 350 \times 70^3}{60} + \frac{126 \times 35^3}{4}$$

from symmetry $M_2 = M_3 = 152{,}000$ lb-in.

$R_1 = R_4 = 14{,}800$ lb $\quad R_2 = R_3 = 17{,}000$ lb

Mid-span moment M = -235,600 lb-in.

Max. shear = 14,800 lb

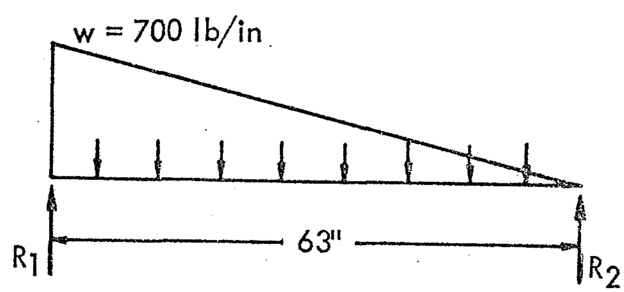
Diagonal Beam No. 3

This beam is pin ended and loaded.

$$\text{Max } M = .128 \frac{w\ell^2}{2}$$

$$= \frac{700 \times 63^2 \times .128}{2}$$

$$= 178{,}000 \text{ in-lb}$$



$R_1 = 14{,}7000$ lb

$R_2 = 7{,}350$ lb

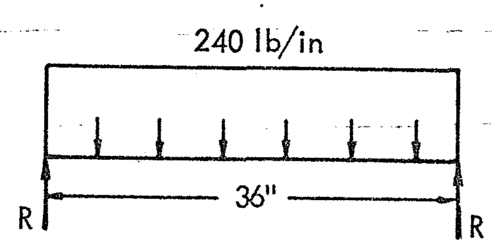
Typical Cross Beam No. 5

This beam is also pinned at each end and loaded as shown.

The maximum bending moment,

$$M = \frac{w\ell^2}{8} = \frac{240 \times 36^2}{8} = 39{,}000 \text{ lb-in.}$$

$R = 2110 \times 18 = 4{,}310$



Post Load

The posts provide a tension tie between the beams of adjacent floors. The maximum tensile load,

From main beams = 2 x 17,000 = 34,000 lb

From diagonal beams = 7,350 lb

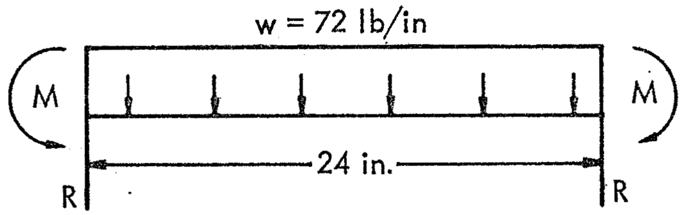
Total tension = 41,350 lb

The maximum compression transferred between adjacent floors results from ground handling loads. This force is:

$$P_c = \frac{\pm 20{,}000 \times .48}{2} = \pm 4{,}800 \text{ per post.}$$

Integral Floor Stiffeners

The maximum spacing of floor stiffeners is 5.16 in., and their length = 24 in. as fixed ended beams, with loading as shown.



$$\text{Max. } M = \frac{w\ell^2}{12} = \frac{72 \times 24^2}{12} = 3{,}460 \text{ lb-in.}$$

$$R = 72 \times 12 = 864 \text{ lb}$$

Table 3-15 presents a condensed summary of the loads that must be supported by the floor members. Ground handling loads have been added to pressure loads to permit complete ground checkout under simulated orbital conditions. If pressure and handling loads are not added, a small saving in weight can be realized in beam No. 1.

Table 3-15.

SUMMARY OF FLOOR LOADS

Member \ Condition		Pressure Moment lb-in.	Pressure Shear lb.	Ground Handling Moment lb-in.	Ground Handling Shear lb.	Net Design Moment lb-in.	Net Design Shear lb.
Beam No. 1	at Post	152,000		96,500		248,500	
	at 35 in.	235,600		48,200		283,800	
8 in. deep	at end	--	14,800	--	2,660		17,460
Beam No. 3 8 in. deep		178,000	14,700	--	--	178,000	14,700
Beam No. 5 4 in. deep		39,000	4,310	--	--	39,000	4,310
Stiffener		3,460	864	--	--	3,460	864

Stresses and Margins of Safety

The beam upper caps are machined integrally with the floor surface from 2219-T87 aluminum plate. The lower caps are 7075-T6 extrusions. The webs are fabricated from epoxy pre-impregnated glass cloth conforming to specification LAC C-22-978. These fiberglass webs are used in preference to aluminum webs with thermally insulating shims to maximize the heat leakage path. Even with the fiberglass webs, 90 percent of the module heat loss is through the structure.

The allowable material stresses as specified in Reference 4 are:

	F_{tu}	F_{cu}	F_{su}
2219-T87 plate (Floor flange)	58,000	58,000	34,000
7075-T6 plate (Lower flange)	75,000	75,000	45,000
Glass fabric epoxy (Web)	--	--	9,200

For the compression flange, $b/t < 4$, therefore the cripping stress, $F_c = 50,000$ psi.

Table 3-16 shows the principal structural design characteristics of the floor beams.

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Table 3-16

FLOOR BEAM FLANGE AND WEB DATA

Beam Caps Beam	M lb-in.	h in.	P=M/h lb	F_c psi	Area =P/F $in.^2$	Actual A $in.^2$	Margin of Safety
No. 1 at Post	248,500	8	31,000	50,000	.620	.625	.005
at 35 in.	283,800	8	35,500	50,000	.710	.720	.01
No. 3	178,000	8	22,300	50,000	.446	.450	.01
No. 5	39,000	4	9,780	50,000	.196	.200	.02

Beam Webs (shear)*

Beam	Shear lb	q lb/in.	$\frac{F_{su}}{1.33}$	Thickness $t=1.33q/F_{su}$ in.	Actual t in.	Margin of Safety
No. 1	16,180	2020	6,920	.293	.34	.16
No. 3	14,700	1840	6,920	.266	.28	.05
No. 5	4,310	1075	6,920	.156	.16	.03

*For the fiberglass webs, the ultimate shear strength is divided by 1.33 to allow for fabrication variables.

Integral Floor Stiffeners

The stiffener is a compact section 1.25 in. x .18 in. with an allowable bending modules of rupture - 85,000 psi (Ref. 4, SM53-C). From the sketch above (Integral Floor Stiffeners):

$$f_b = \frac{6M}{th^2} = \frac{6 \times 3,460}{.18 \times 1.25^2} = 74,000 \text{ psi}$$

$$\text{Margin of safety} = \frac{85,000}{74,000} - 1 = .15$$

Support Posts

The support posts constitute tension ties between the floor and the ceiling. They are also capable of carrying compression loads between these structures. The material is 7075-T6 aluminum tubing. The loads and stresses are as follows:

Maximum tensile load = 41,350 lb

Maximum compressive load = 4,800 lb

For a 3 in. diameter tube with a .058 in. wall, the cross-sectional area, $A = .536\ in^2$

$$P/A = \frac{41,350}{.536} = 77,000\ psi$$

$$F_{tu} = 77,000 \text{ for 7075-T6 tube}$$

$$\text{Margin of safety} = \frac{77,000}{77,000} - 1 = 0$$

3.3.2.6 <u>Module Hatches</u>

<u>Flat Integrally Stiffened Waffle Grid Hatch</u>

The maximum bending stress on a simply supported flat circular plate with a uniform loading is from Ref. 3.3-6.

$$f_b = \frac{3W}{8\pi m t^2}(3m+1)$$

The bending stress for a flat plate is $f_b = \frac{6M}{t^2}$

where $W = P\pi R^2$

P = uniform pressure = 14 psi ult.

R = plate radius = 18 in.

t = plate thickness (in.)

$m = \frac{1}{v}$ = 3.0 for aluminum

M = bending moment (in-lb/in)

Then, $\frac{3PR^2(3m+1)}{8mt^2} = \frac{6M}{t^2}$, and

$$\text{Maximum bending moment} = \frac{3PR^2(3m+1)}{48m} = 945\ \text{in-lb/in.}$$

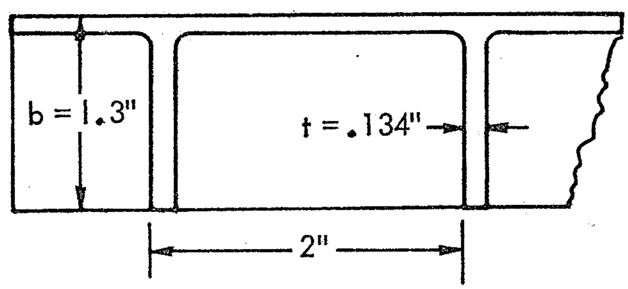
The maximum bending stress on the stiffeners is,

$$f_b = \frac{6M}{t\,b^2} = \frac{6 \times 2 \times 945}{.134 \times 1.69} = 50{,}000 \text{ psi}$$

The hatch is a flat 2219-T87 aluminum alloy plate with a waffle grid of integral stiffeners spaced 2 in. on centers in the maximum moment area as shown.

For 2219-T87 aluminum, $F_b = 50{,}000$ psi

Therefore, margin of safety $= \frac{50{,}000}{50{,}000} - 1 = 0$



Spherical Dome Hatch

A hatch design utilizing a spherical dome is loaded with uniform pressure on the convex side (radius, R = 18.4 in)

The critical collapsing pressure P_{cr} is,

$$\frac{P_{cr}}{E} = \frac{.606}{\left(\frac{R}{t}\right)^2 e^{(.045\sqrt{R/t})}}$$

Let $P_{cr} = 14$ psi ult.

$$\frac{P_{cr}}{E} \times 10^8 = \frac{14 \times 10^8}{10^7} = 140$$

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From Fig. 3-37:

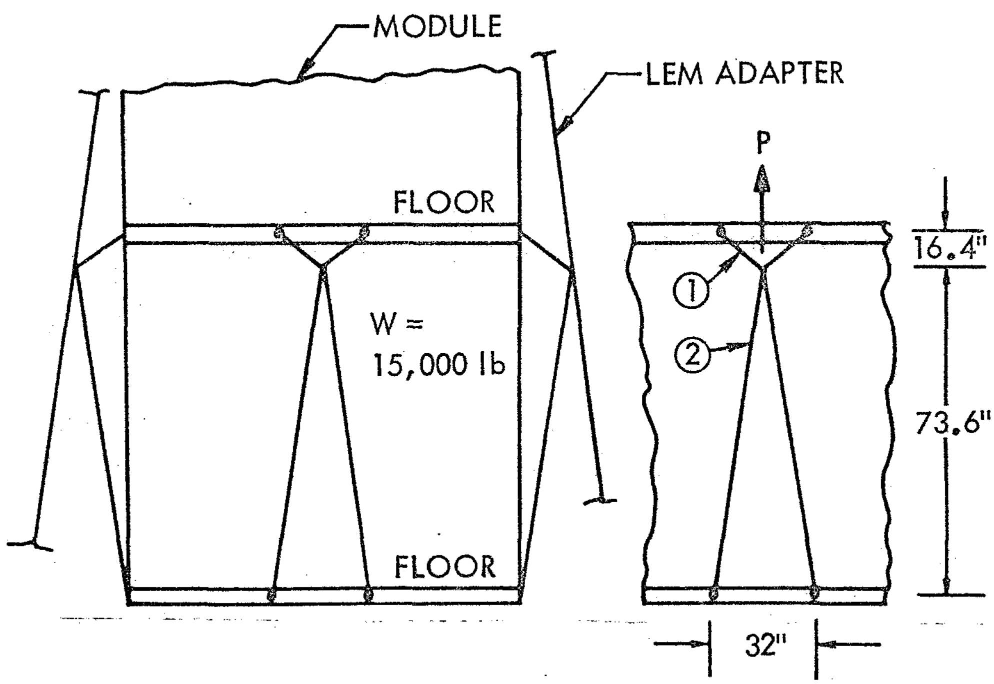
$$R/t = 430$$

Required thickness $t = \frac{18.4}{430} = .043$ min. skin gage of aluminum.

The spherical dome hatch is lighter than the flat surface design and is therefore the preferred configuration.

3.3.2.7 Support of the Module in the LEM Adapter

The four-point support of the module is stabilized by members that attach to the periphery of the module at the floor levels, shown in this sketch.



The ultimate load results at second stage burnout during launch.

$$N_u = 7.5g$$

$$\text{Ult. } P = \frac{15{,}000 \times 7.5}{4} = 28{,}100 \text{ lb per truss}$$

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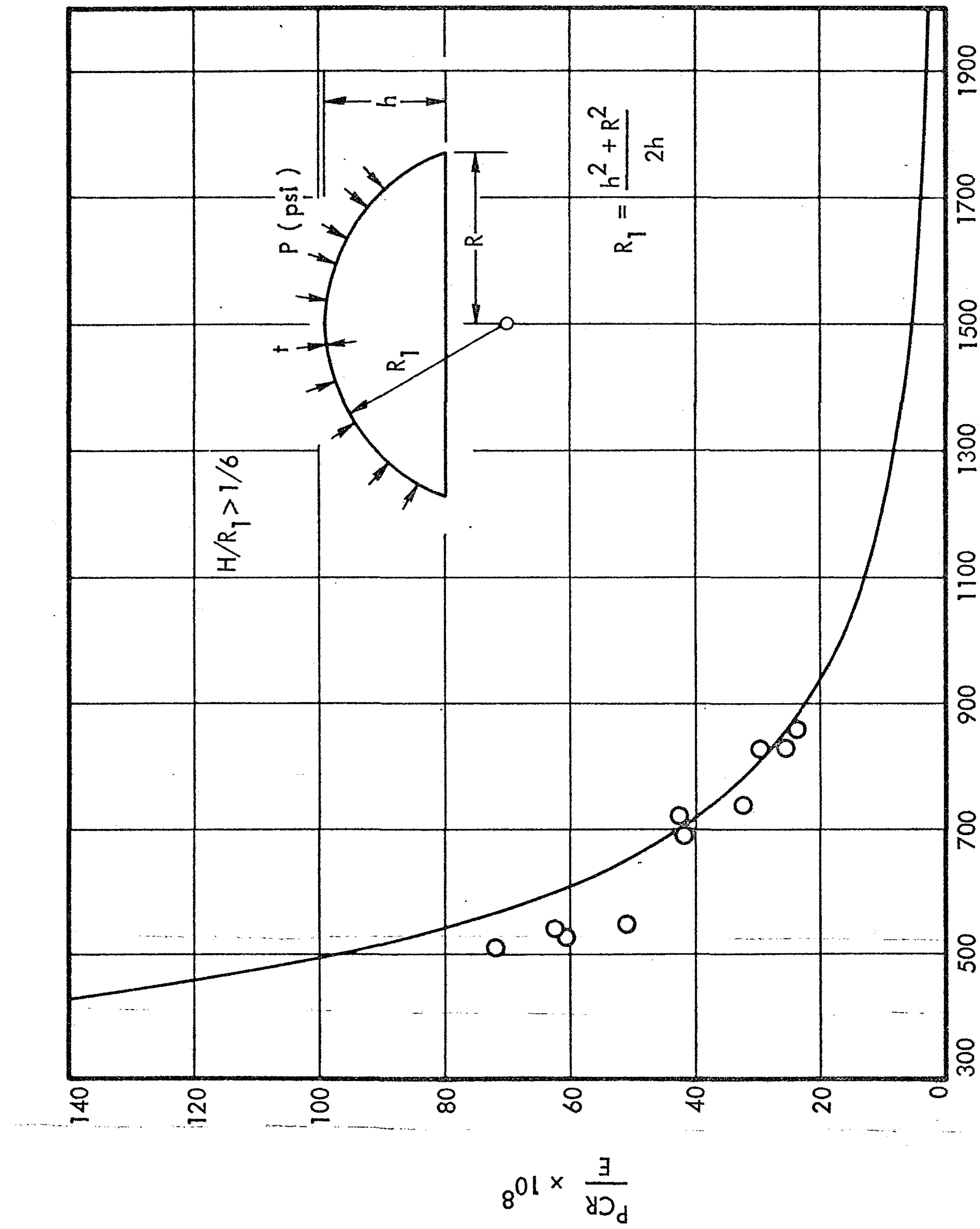

FIG. 3-37 ELASTIC BUCKLING PRESSURES OF NONSHALLOW SPHERICAL CAPS LOADED WITH EXTERNAL PRESSURE

The truss member loads are:

No. 1 top member P_1 = -5,470 lb (compression)

No. 2 bottom member P_2 = 12,300 lb tension.

Design of Truss Tubes

The vertical component of the truss load is transmitted directly to the module integral stiffeners, by means of four channels that are externally located on the shell at the floor levels. The horizontal load components are balanced out through the channel. Design data are given in Table 3-17. All material is 2219-T87 aluminum alloy.

Table 3-17
TRUSS TUBE DATA

Tube Member	Cross Sectional Area, A (in.^{2})	Radius of Gyration ρ (in.)	$\frac{P}{A}$	$\frac{Length}{\rho}$	Allowable Column Stress F_c (psi)	Margin of Safety
No. 1 $1\frac{1}{2}$ x .049	.223	.51	24,500	56	28,000(1)	.14
No. 2 2 x .049	.300	.69	41,000	105	42,000(2) (welded)	.02

Ref. (1) Lockheed SMM 836.
(2) Alcoa Data.

REFERENCES-Section 3.3

3.3-1 Lockheed Technical Memorandum Report 50737, Basis for Structural Design for LORL, dated 12 June 1964.

3.3-2 Lockheed Technical Memorandum Report 50290, Basis for Structural Design, Small Space Station, dated Dec. 28, 1962.

3.3-3 Meteoroid Evironment in Near-Earth, Cislunar and Near-Lunar Space, NASA-MSC Engineering Criteria Bulletin, Serial No. EC-1, dated 8 November 1963.

3.3-4 Engineering Stress Memo Manual, The Lockheed-California Company.

3.3-5 Weight-Strength Analysis of Aircraft Structures, Second Edition, By F. R. Shanley, Dover Publications, Inc.,New York, New York.

3.3-6 Formulas for Stress and Strain, Roark, 2nd Edition, page 188.

3.4 WEIGHT ANALYSIS

The weight data developed herein reflects the concept of sequential evolution of a family of multipurpose space stations. Emphasis throughout is on the modularization of laboratory structure and supporting subsystems. An important objective is to provide a method of readily assessing payload compatibility of a broad spectrum of experiments with generally defined, mission-oriented laboratory configurations.

The term "discretionary payload" is used throughout the following discussion as a weight item indicative of the mission capability of a particular configuration. Discretionary payloads are those items to which discretion can be applied in mission planning, e.g., expendable mission supplies, containers and tankage, spares, and experimental equipment. Thus, possible experimental payloads and mission stay times can be parametrically determined by proper definition of initial laboratory launch configuration, discretionary payload available, crew size, and logistic requirements.

Published information* is used as a basis for the three-man Apollo Command and Service Module configuration and weights for missions where the Apollo is launched with the space station. The main weight differences for the various missions appear in the Service Module electrical power, reaction control and propulsion systems.

Table 3-18 shows a comparison of the various three-man Apollo configuration weights. A nominal 1.5-kw fuel cell system is provided in both the Service Module and the laboratory for the one compartment, 45-day, low inclination, earth orbit mission. Fuel cells are replaced by a nominal 5-kw, laboratory mounted solar array on the two compartment configurations. The back-up battery in the Service Module is retained for emergency power in case of failure of solar power subsystem. Various combinations of Apollo X and Block II reaction control and propulsion

*North American Aviation, "Extended Apollo Systems Utilization Study, Final Report, Vol. 4 - Configurations, Structures and Weights, SID 64-1860-4, 16 Nov. 1964.

Table 3-18

THREE-MAN APOLLO COMMAND AND SERVICE MODULE WEIGHT SUMMARY

Item	1 Compt. 28.5 deg 200 n. miles	2 Compt. 28.5 deg 200 n. miles	2 Compt. Polar 200 n. miles	2 Compt. 30 deg 19,380 n. miles
COMMAND MODULE	9600	9600	9600	9600
Structure	4684			
Reaction Control (incl. 270 lb prop.)	609			
Electrical Power	614			
Electronics	1194			
Communication	(367)			
Instrumentation	(198)			
Control & Displays	(373)			
Guidance & Navigation	--	No Change	No Change	No Change
Stabilization & Control	(256)			
Environmental Control (incl. 68 lb O_2)	409			
Crew Accommodations	1347			
Crew, Suits & Life Supt. Packs	(774)			
Misc. Couches, Etc.	(550)			
Food	(23)			
Earth Landing Provisions	743			

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Table 3 -18 (con't)

THREE-MAN APOLLO COMMAND AND SERVICE MODULE WEIGHT SUMMARY (Cont.)

Item	1 Compt. 28.5 deg 200 n. miles	2 Compt. 28.5 deg 200 n. miles	2 Compt. Polar 200 n. miles	2 Compt. 30 deg 19,380 n. miles
SERVICE MODULE	7090	6350	6130	6630
Structure	2451	2451	2451	2451
Reaction Control	596	1237	1017	596
Engine System	(175)	(175)	(175)	(175)
Tank System	(421)	(1062)	(842)	(421)
Reactants	*	*	*	*
Electrical Power	1631	250	250	250
Battery & Distribution Sys.	(250)	(250)	(250)	(250)
Fuel Cell System	(1381)	--	--	--
Tanks & Reactants	*	*	*	*
Electronics-Comm. & Instr.	214	214	214	214
Environmental Control	259	259	259	259
System	(259)	(259)	(259)	(259)
Tanks & Reactants	*	*	*	*
Propulsion	1939	1939	1939	2860
Engine System	(774)	(774)	(774)	(774)
Tanks & Residuals	(1165)	(1165)	(1165)	(2086)
Reactants	**	**	**	**
Total Command & Service Module	16,690	15,950	15,730	16,230

*Included in discretionary payload
**Ascent and retro propellant listed in launch configuration weight summary

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tankages compatible with mission requirements are indicated as fixed and the reactants are off-loaded. For the purpose of this study, environmental control and fuel cell consumables and tankage are optimized and reflected as a time rated portion of discretionary payload.

Table 3-19 shows a comparison of the supply requirements for the different missions. For this study, the following consumable rates have been established as common for all configurations: personal accommodations at 0.5 pound per man-day packaged and food at 1.3 pounds per man-day packaged. The environmental control system rate of 28.2 pounds per day for the one compartment, 3-man, 45-day mission reflects the use of lithium hydroxide for carbon dioxide removal and a single gas oxygen atmosphere at 5 psia. All the remaining configurations employ a molecular sieve for carbon dioxide removal and a two gas atmospheric environment at a normal pressure of 7 psia. Oxygen regeneration is initiated with the Interim Space Station; recovery of oxygen from carbon dioxide results in a weight saving of 1.37 pounds per man-day. Processing of fecal water for oxygen recovery results in an additional saving in the Operational Space Station of 0.17 pounds per man-day.

The rates given for the reaction control system consumables are for orbit maintenance and normal stability and control. Various combinations of Block II and LEM tankage with adequate capacity for the associated missions are indicated as fixed in the weight of the Apollo Service Module for one and two compartment configurations. The propellant rates for the Interim and Operational stations include a 10-percent tankage factor. Control moment gyros in the two-compartment and larger configurations contribute to propellant economy for normal stability and anticipated experimental requirements.

The consumption of 60 pounds per day for the one compartment fuel cell reactants includes 43-percent tank factor and a 25-percent reserve factor. This rate gives a total of 1620 kw-hr for a 45-day period at an average operating rate of 1.5 kw and a specific fuel consumption of 0.93 lb/kw-hr.

Table 3-19

MULTI-PURPOSE SPACE STATION RESUPPLY REQUIREMENTS

Item	One Compartment Dependent Laboratory	Two Compartment Independent Laboratory	Two Compartment Polar Laboratory	Two Compartment Synchronous Laboratory	Interim Modular Multipurpose Space Station	Operational Modular Multipurpose Space Station
Crew Size	3	6	3	3	9	24
O_2 System	Storable	Storable	Storable	Storable	Regen.	Regen.
CO_2 Removal	LiOH	Molecular Sieves	Molecular Sieves	Molecular Sieves	Molecular Sieves	Molecular Sieves
Time (days) + Contingency (days)	45 + 5	90 + 90	90 + 30	90 + 45	90 + 90	90 + 90
Weight						
ECS - Reactants & Containers (lb/day)	28.2	24.3	17.8	17.8	25.2	43.4
Personal Accom. at .5 lb/man-day Packaged	1.5	3.0	1.5	1.5	4.5	12.0
Food-Packaged at 1.3 lb/man-day	3.9	7.8	3.9	3.9	11.7	31.2
RCS (lb/day)	11.6	19.1*	12.1*	6.4*	33.0**	77.8**
Fuel Cell-Tanks & Reactants & 25% Res. (lb/day)	60.0	--	--	--	--	--
Spares (lb/day)	3.0	6.0	3.0	3.0	9.0	36.3
TOTAL	108.2	60.2	38.3	32.6	83.4	200.7

*Tanks are fixed in the Service Module and the reactants are off-loaded.
**Initial supply is in Laboratory. The tanks and reactants are optimized.

Tables 3-20 through 3-25 present summary weight statements and graphic representation of discretionary payload for an optional range of experimental equipment weights and mission durations for the six space systems studied. Initial discretionary payload capability, the number of logistic launches, if any, to man the station fully for initial operation, and resulting logistic payload capability establish the trade-off limits.

Refer to Table 3-21 "Two-Compartment Independent Laboratory" as an illustration of the information to be extracted. The Saturn IB has an effective launch capability of 36,800 pounds to 80 n. miles and 28.5-deg inclination as discussed in Section 3.1. The laboratory subsystems, including structure, weigh 5400 pounds dry, less tankage. The LEM adapter, which is jettisoned at 80 n. miles before the Hohmann transfer to the 200-n. mile circular orbit, weighs 3500 pounds. Propellant required for orbit injection and re-entry maneuvering is stored in the Service Module tanks and weighs 2500 pounds. The three man Command and Service Module configuration that is detailed in Table 3-18 for this mission weighs 15,950 pounds. Deducting these weight items from the effective launch capability leaves 2,120 pounds for the initial discretionary payload requirement for mission consumables, containers, spares and experimental equipment. As indicated, one three-man logistic launch with a discretionary payload capability of 16,800 pounds is required to man the laboratory fully for normal operation.

Table 3-19 indicates that the supply requirement for this two compartment laboratory configuration is 60.2 pounds per day. If an arbitrary mission duration of 90 days plus 90 days of reserve supplies is chosen, an experimental payload capability of 8080 pounds results when the supply requirement is deducted from the accumulated discretionary payload capability of 18,920 pounds.

Table 3-20

ONE-COMPARTMENT DEPENDENT LABORATORY, SUMMARY WEIGHT STATEMENT AND DISCRETIONARY PAYLOAD ALLOCATION

Item	Weight (lb)
Laboratory Subsystems-Dry	5400
Structure	(2810)
Environmental Control	(700)
Electrical Power	(1440)
Reaction Control	-
Communications	(10)
Data Management	(60)
Navigation & Guidance	(10)
Stabilization & Control	-
Display Panels & Instrumentation	(150)
Crew Prov., Furnishings & Trim	(220)
LEM Adapter	3500
Apollo Command & Service Module	16,690
Propellant	2500
Discretionary Payload*	8710
Effective Launch Capability	36,800

*Discretionary Payload includes mission consumables, containers, spares and experimental equipment.

Discretionary Payload

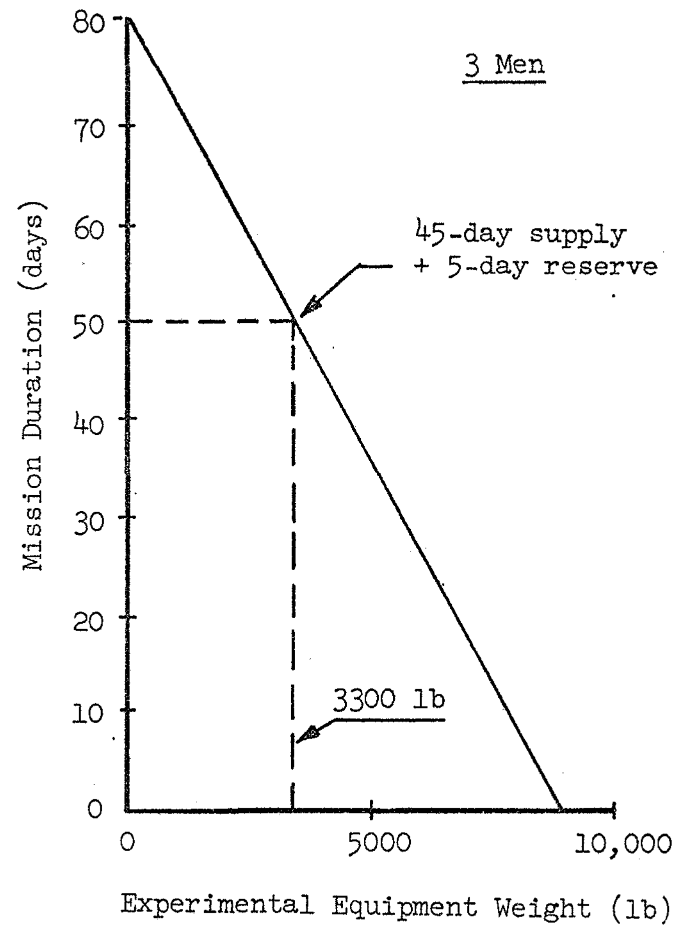
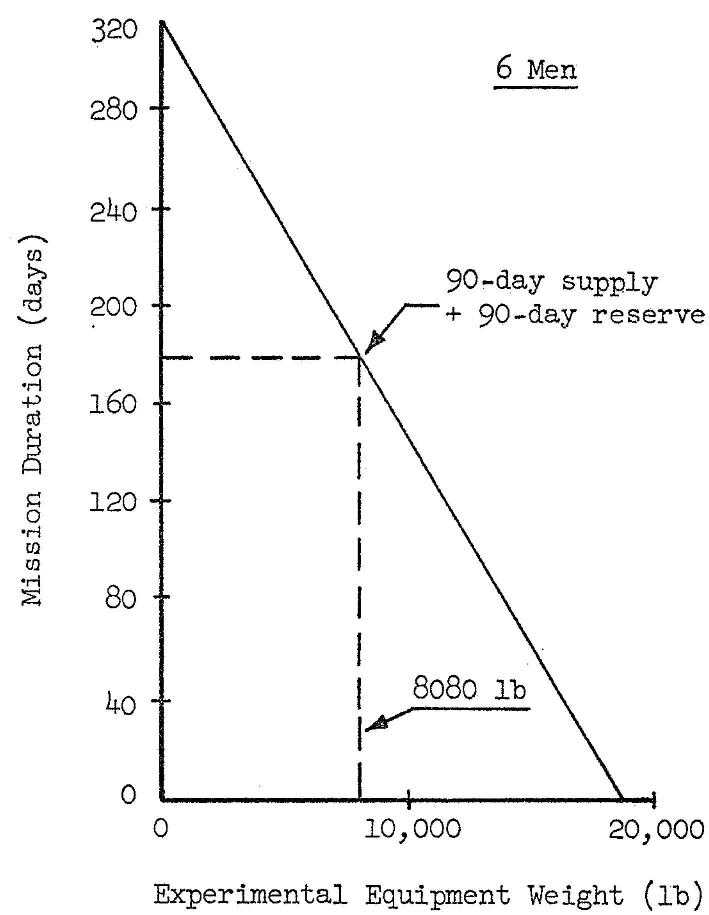


Table 3 -21

TWO-COMPARTMENT INDEPENDENT LABORATORY, SUMMARY WEIGHT STATEMENT AND DISCRETIONARY PAYLOAD ALLOCATION

Item	Weight (lb)
Laboratory Subsystems-Dry	12,730
Structure	(4480)
Environmental Control	(1270)
Electrical Power	(3200)
Reaction Control	(180)
Communications	(380)
Data Management	(180)
Navigation & Guidance	(300)
Stabilization & Control	(370)
Display Panels & Instrumentation	(230)
Crew Prov., Furnishings & Trim	(1340)
Radiation Shield Prov.	(800)
LEM Adapter	3500
Apollo Command & Service Module	15,950
Propellant	2500
Discretionary Payload*	2120
Effective Launch Capability	36,800

Discretionary Payload
(Initial + One Logistic Launch)



*Logistic Discretionary Payload per launch is 16,800 lb in addition to the 2120 lb shown. Discretionary Payload includes mission consumables, containers, spares and experimental equipment.

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Table 3-22

TWO-COMPARTMENT POLAR LABORATORY, SUMMARY WEIGHT STATEMENT AND DISCRETIONARY PAYLOAD ALLOCATION

Item	Weight (lb)
Laboratory Subsystems-Dry	14,110
Structure	(4480)
Environmental Control	(1270)
Electrical Power	(3200)
Reaction Control	-
Communications	(380)
Data Management	(180)
Navigation & Guidance	(330)
Stabilization & Control	(380)
Display Panels & Instrumentation	(230)
Crew Prov., Furnishings & Trim	(1340)
Radiation Shield Prov.	(2320)
LEM Adapter	3500
Apollo Command & Service Module	15,730
Propellant	1500
Discretionary Payload*	6160
Effective Launch Capability	41,000

*Discretionary Payload includes mission consumables, containers, spares and experimental equipment.

Discretionary Payload

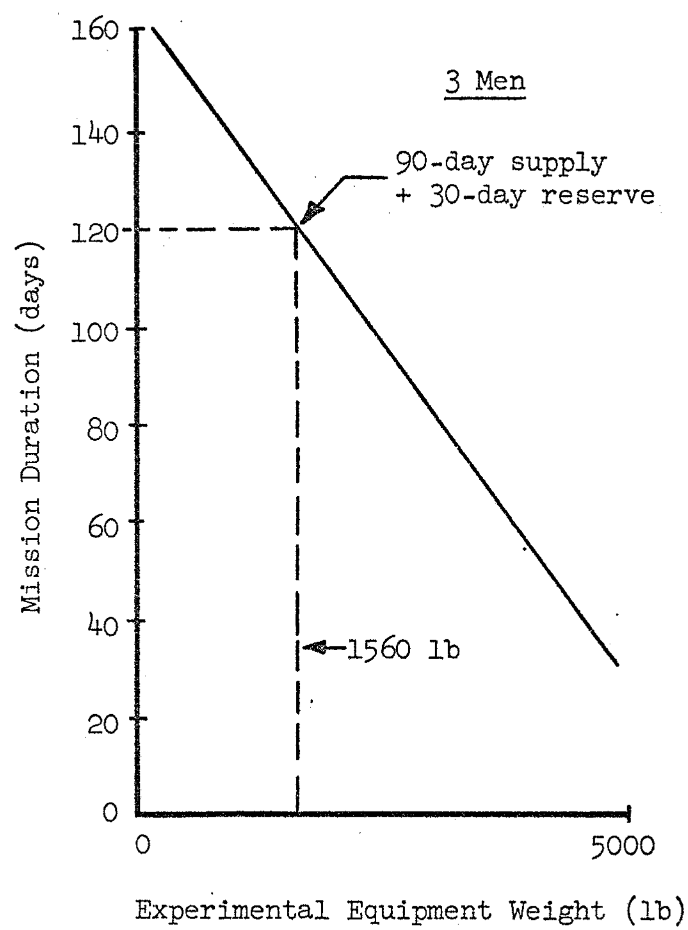

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Table 3-23

TWO-COMPARTMENT SYNCHRONOUS LABORATORY, SUMMARY WEIGHT STATEMENT AND DISCRETIONARY PAYLOAD ALLOCATION

Item	Weight (lb)
Laboratory Subsystems-Dry	12,400
Structure	(4480)
Environmental Control	(1270)
Electrical Power	(1800)
Reaction Control	-
Communications	(380)
Data Management	(140)
Navigation & Guidance	(280)
Stabilization & Control	(50)
Display Panels & Instrumentation	(230)
Crew Prov., Furnishings & Trim	(1340)
Radiation Shield Prov.	(2430)
LEM Adapter	3500
Apollo Command & Service Module	16,230
Propellant	16,000
Discretionary Payload*	14,870
Effective Launch Capability	63,000

*Discretionary Payload includes mission consumables, containers, spares and experimental equipment.

Discretionary Payload

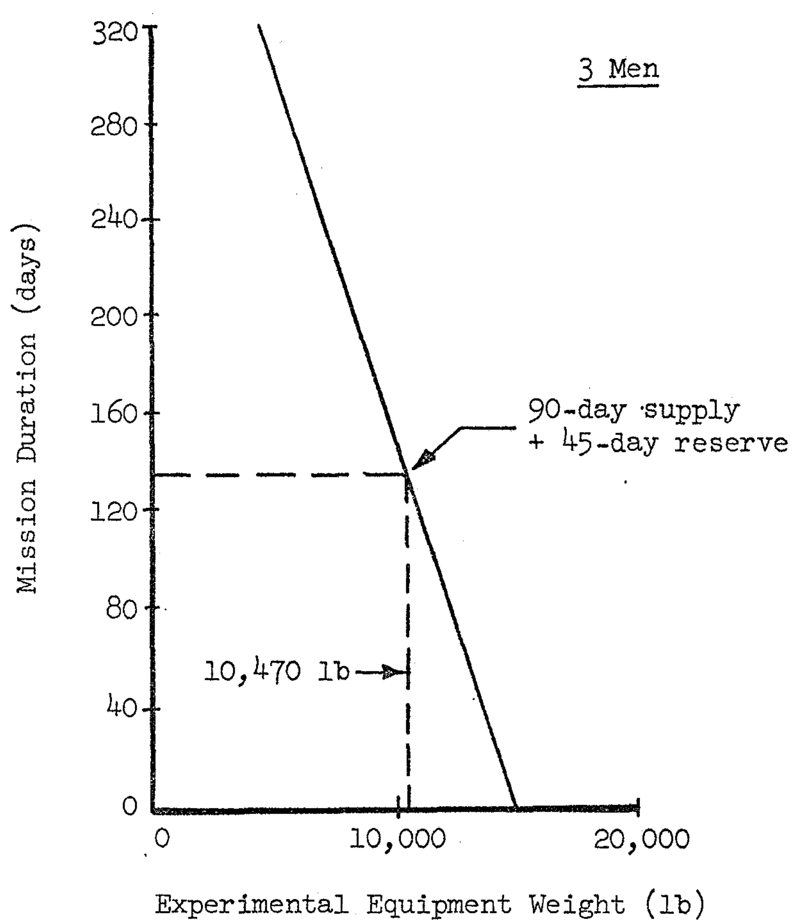

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Table 3-24

INTERIM MODULAR MULTIPURPOSE SPACE STATION, SUMMARY WEIGHT STATEMENT AND DISCRETIONARY PAYLOAD ALLOCATION

Item	Weight (lb)
Laboratory Subsystems-Dry	26,510
Structure	(10,480)
Environmental Control	(2450)
Electrical Power	(7620)
Reaction Control & Orbit Injection	(330)
Communications	(1170)
Data Management	(230)
Navigation & Guidance	(230)
Stabilization & Control	(690)
Display Panels & Instrumentation	(460)
Crew Prov., Furnishings & Trim	(1650)
Radiation Shield Prov.	(1200)
Fairings-Jettisoned	1830
Laboratory Startup Provisions	1160
Orbit Injection Fuel & Tanks	1700
Discretionary Payload-Initial*	5600
Effective Launch Capability	36,800

*Logistic Discretionary Payload per launch is 16,800 lb. Discretionary Payload includes mission consumables, containers, spares and experimental equipment.

Discretionary Payload
(Initial + 3 Logistic Launches)

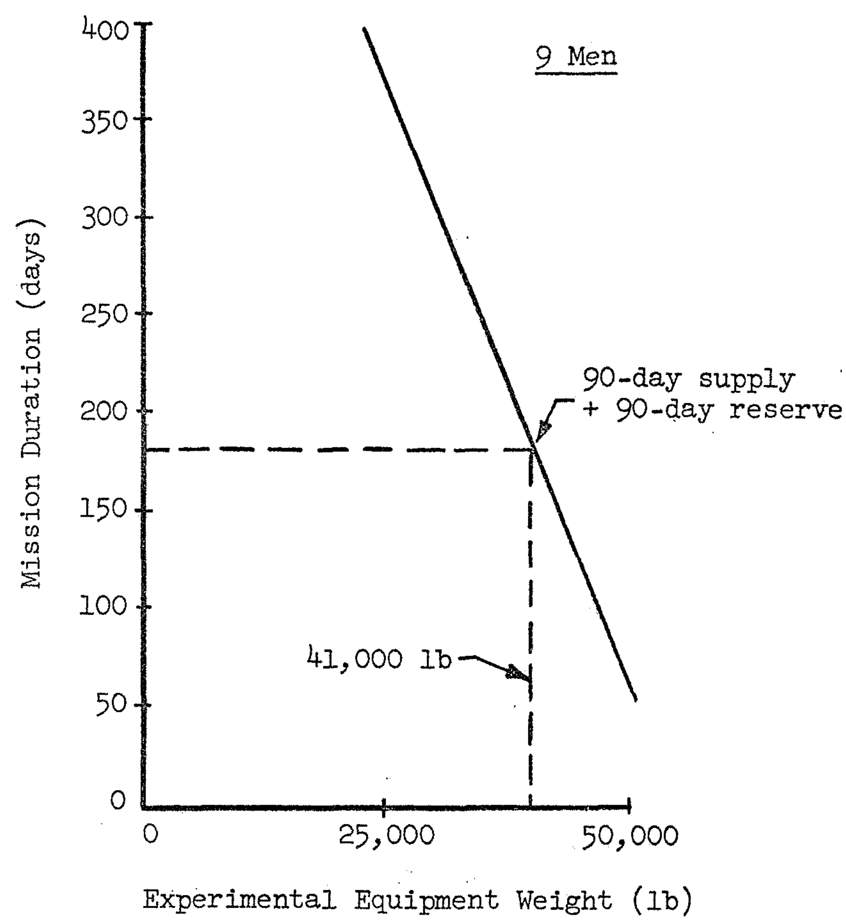

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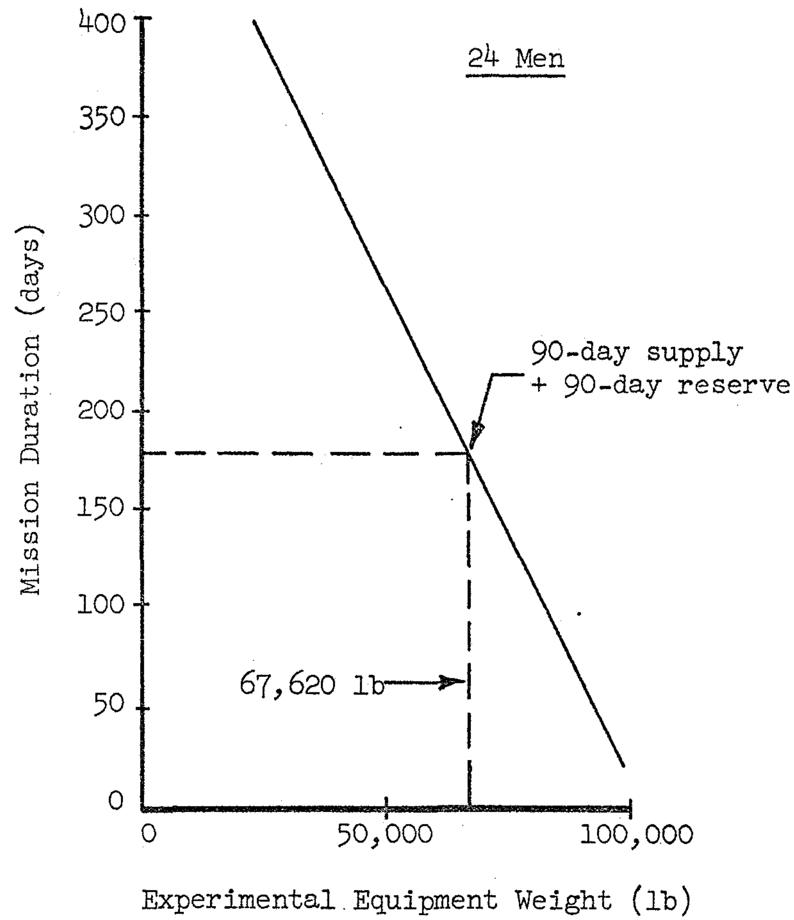
Table 3-25

OPERATIONAL MODULAR MULTIPURPOSE SPACE STATION, SUMMARY WEIGHT STATEMENT AND DISCRETIONARY PAYLOAD ALLOCATION

Item	Weight (lb)
Laboratory Subsystems-Dry	160,210
Structure	(107,660)
Environmental Control	(9400)
Electrical Power	(20,640)
Reaction Control	(1150)
Communications	(2210)
Data Management	(580)
Navigation & Guidance	(300)
Stabilization & Control	(5000)
Display Panels & Instrumentation	(1830)
Crew Prov., Furnishings & Trim	(6600)
Radiation Shield Prov.	(4840)
Fairings-Jettisoned	1200
Laboratory Startup Provisions	4650
Orbit Injection System, Fuel & Tanks	8700
Discretionary Payload-Initial*	72,740
Effective Launch Capability	247,500

*Logistic Discretionary Payload per launch is 15,500 lb. Discretionary Payload includes mission consumables, containers, spares and experimental equipment.

Discretionary Payload
(Initial + 2 Logistic Launches)



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Applying this procedure to all six configurations results in the following payoff in mission duration and experimental payload capability.

Table Reference	Configuration	Mission Duration + Reserves (days)	Experimental Payload (lb)
3-20	One-Compartment Dependent Lab.	45 + 5	3300
3-21	Two-Compartment Independent Lab.	90 + 90	8080
3-22	Two-Compartment Polar Lab.	90 + 30	1560
3-23	Two-Compartment Synchronous Lab.	90 + 45	10,470
3-24	Interim Modular Multipurpose Space Station	90 + 90	41,000
3-25	Operational Modular Multipurpose Space Station	90 + 90	67,620

Strict adherence to the modular concept dictates that the structure of each module be capable of sustaining the most severe loads encountered in any module in the family of stations. Table 3-26 presents a weight comparison of modularized one, two, and six compartment structural assemblies. It is possible, however, to optimize the lateral rings and stiffeners for a 300 and 520 pound weight saving respectively, when the one or two compartment laboratory configurations are launched inside the LEM adapter. Table 3-27 shows the structural weights of the one and two compartment configurations optimized for the loads encountered only on those configurations.

Various floor designs were developed in sufficient detail to recognize the particular problems and advantages of each. Domed ends for the modules were eliminated to reduce the number of different structural components. Further, since all floors must resist the 7-psi atmosphere, a pressure-carrying dome becomes a redundant structural member. Honeycomb sandwich (4- and 6-inch thick) and integrally stiffened, beam-supported floors were also considered. Table 3-28 lists the principal details and weights of each of these three floor designs. The principal advantage of the integrally stiffened, beam floor is a weight saving of 136 pounds; however, Table 3-29 indicates other comparisons between honeycomb and beam designs and the reasons for selection of the beam supported floor design.

Although the 183-inch diameter module was chosen as the primary design, alternate 260-inch diameter modules were investigated. A graphic comparison of structural weight and volume as a function of the number of compartments for the two approaches is presented in Figs. 3-38 and 3-39. A 90-inch floor pitch is maintained in all cases. A one-compartment, 183-inch diameter module weighs 6310 pounds, with the 3500 pound LEM adapter included, and has pressurized volume of 1250 cubic feet. On a comparable basis, the 260-inch diameter gives a structure weight of 8880 pounds and a 2500 cubic foot volume. Preliminary investigation has indicated that a 260-inch diameter, two-compartment module with the Apollo would be marginal from a weight standpoint for near earth launch with the Saturn IB.

The Interim Space Station yields a structural weight, with fairings, of 12,310 pounds and a volume of 7500 cubic feet with the 183-inch diameter. A 260-inch diameter of equivalent volume would require three compartments and cost 13,370 pounds in structural weight. The MORL point design, referred to in Table 3-30 is a 260-inch diameter laboratory with a structural weight of 16,000 pounds and a volume of 9000 cubic feet. This would be comparable to 3 to 4 compartment sizing on the weight and volume curves.

Some main design highlights for the MORL point reference configuration and the six compartment modular counterpart are compared in Table 3-30. Subsystem weights are compared in more detail in Table 3-31. The basic MORL has six-man subsystems with a nine-man overload capability. The electrical power system is nominally rated at 6 kw and the environmental control consumables are non-recoverable. The six compartment Interim modular station subsystems are sized for nine men with oxygen regeneration as an integral part of the life support system. The solar array electrical power system can supply 10 kw average power for subsystem and experimental requirements. A 1-kw fuel cell is available for station start-up and emergencies. The 1200 pounds allowed for localized radiation shielding could possibly be reduced if the protection afforded by local equipment could be properly evaluated.

Based on the same Saturn IB launch vehicle capability, 36,800 pounds to 80 n. miles and the same orbit altitude of 200 n. miles, the initial discretionary payload capability for MORL is 8480 pounds and 6760 pounds for the modular approach. Included is 1160 pounds for startup of the modular station.

The three radial module concept of the Operational Multipurpose Space Station is inherently receptive to the benefits of structural and subsystems modularization. Each leg of the rotating space system is composed of a six compartment Interim module, tied into the central hub assembly by a pair of pivoted access tubes. Each of the four segments are capable of accommodating an equal number of men by means of essentially identical subsystems.

Table 3-32 presents a design and weight comparison of a 24-man integrated station design and a 36-man station that is modularized throughout the subsystems and structurally to the extent of splicing single compartment structural segments to form a six compartment radial module. The volume of both designs, including the three radial modules, access tunnels, zero-gravity laboratory, and hangar is 69,530 cu. ft. A comparison of the structural weight for the two designs indicates a 2220 pound increase for splicing single compartment module sections. Subsystems indicate a total weight of 46,320 pounds for the 24-man point design and 52,550 pounds for 36 men. This is an increase of

6230 pounds for the 12 additional men or 520 pounds per man. The resulting initial discretionary payload capability for the 24-man point design, launched to 260 n. miles with a two-stage Saturn V is 85,840 pounds. The capability for the 36-man modular design is 77,390 pounds into the same orbit.

Details of the subsystems weights are compared in Table 3-33. Oxygen regeneration is a feature of the environmental control subsystems of both designs; there is an 1100-pound increase to the dry weight for the addition of 12 men. Crew provisions, trim and furnishings are increased by 1220 pounds and local radiation shielding is increased by 1610 pounds.

A weight in-orbit comparison of the candidate configurations, logistically manned for normal operation, is presented in Fig. 3-40. Supplementary weight data is given in Table 3-34, comparing the different Modular Multipurpose Space Station configurations in orbit.

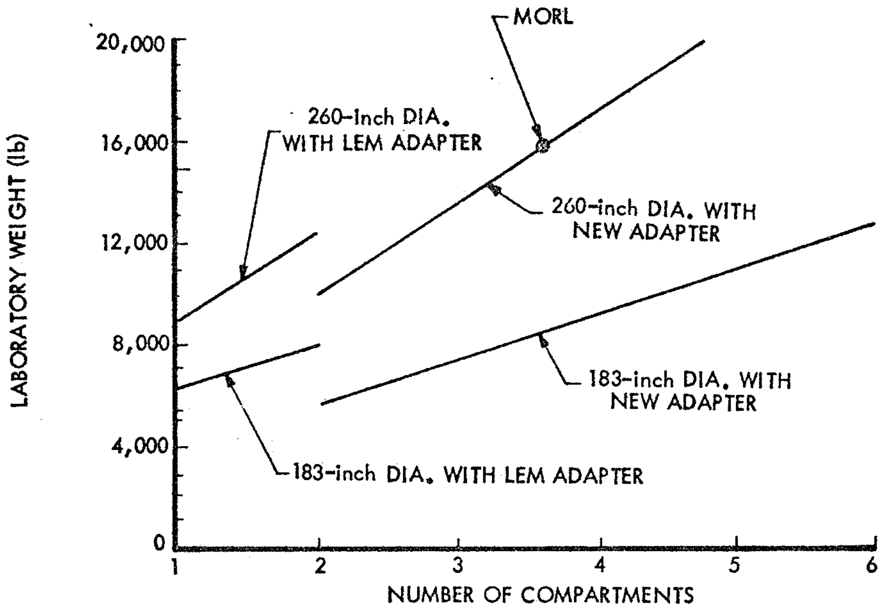

FIG. 3-38 STRUCTURAL WEIGHT VS NUMBER OF MODULAR COMPARTMENTS

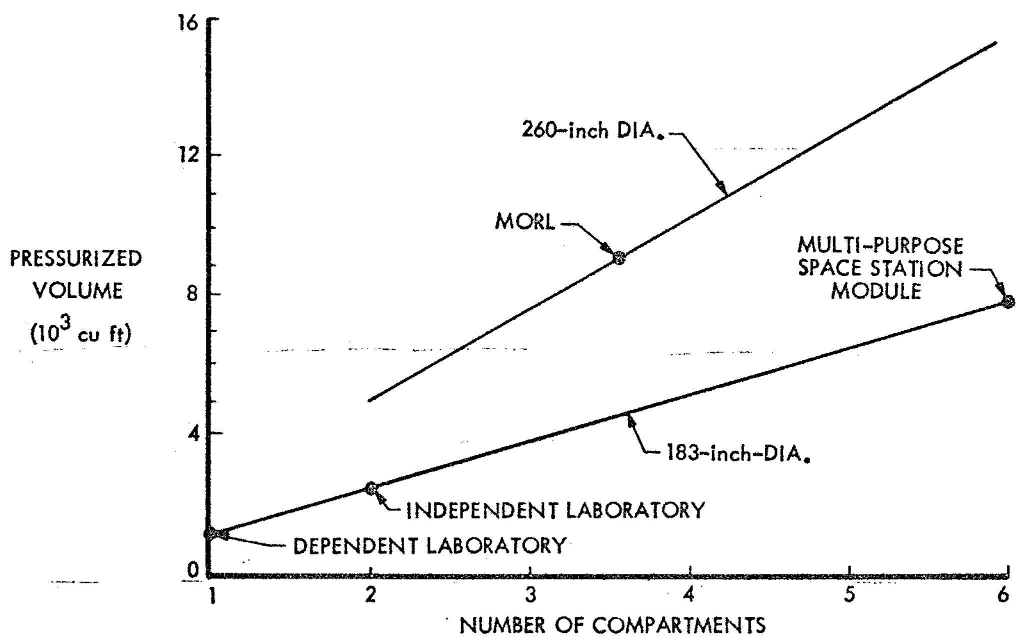

FIG. 3-39 PRESSURIZED VOLUME VS NUMBER OF MODULAR COMPARTMENTS

Table 3-26
STRUCTURAL WEIGHT COMPARISON OF MODULAR CONFIGURATIONS

Item	One-Compartment Laboratory		Two-Compartment Laboratory		Interim Space Station	
	Unit Detail (inches)	Weight (lb)	Unit Detail (inches)	Weight (lb)	Unit Detail (inches)	Weight (lb)
Bulkheads		1,180		1,697		3,625
Pressure Skin	.04 Al 2 Required	(208)	.04 Al 3 Required	(312)	.04 Al 7 Required	(728)
Beams and Stiffeners	306 lb/Blkd.	(612)	306 lb/Blkd.	(918)	291 lb/Blkd.	(2,037)
Meteoroid Skin and Attach. Prov.	.02 Al 2 Required	(116)	.02 Al 2 Required	(116)	.02 Al 2 Required	(116)
Insulation and Attach. Prov.	Al Mylar	(30)	Al Mylar	(30)	Al Mylar	(30)
Joints, Splices, Fasteners & Tolerance	107 lb/Blkd.	(214)	107 lb/Blkd.	(321)	102 lb/Blkd.	(714)
Cylindrical Shell		680		1,360		4,080
Pressure Skin	.037 Al	(220)	.037 Al	(440)	.037 Al	(1,320)
Stiffeners (Al)	.82 x .105 @ 4 c/c	(129)	.82 x .105 @ 4 c/c	(258)	.82 x .105 @ 4 c/c	(774)
Rings (Al)	6 x .064 @ 30 c/c	(75)	6 x .064 @ 30 c/c	(150)	6 x .064 @ 30 c/c	(450)
Meteoroid Skin and Attach. Prov.	.02 Al	(158)	.02 Al	(316)	.02 Al	(948)
Insulation & Attach. Prov.	Al Mylar	(35)	Al Mylar	(70)	Al Mylar	(210)
Joints, Splices, Fasteners & Tolerance		(63)		(126)		(378)
Hatches and Rings - Lateral & Inter. Compt.	2 @ 125 lb	250	5 @ 125 lb	625	12 @ 100 lb 5 @ 75 lb	1,575
Hatches and Rings - Main Docking	2 @ 125 lb	250	2 @ 125 lb	250	2 @ 125 lb	250
Secondary Structure		240		338		950
LEM Adapter Mounting		210		210		
TOTAL		2,810		4,480		10,480

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Table 3-27

MODULE STRUCTURAL WEIGHTS OPTIMIZED FOR INDIVIDUAL MISSIONS

Item	One Compartment		Two Compartment	
	Unit Detail (inches)	Weight (lb)	Unit Detail (inches)	Weight (lb)
Bulkheads		1,180		1,697
Pressure Skin	.04 Al		.04 Al	
	2 Required	(208)	3 Required	(312)
Beams and Stiffeners	306 lb/Blkd.	(612)	306 lb/Blkd.	(918)
Meteoroid Skin and Attachments	.02 Al		.02 Al	
	2 Required	(116)	2 Required	(116)
Insulation and Attachments	Al Mylar	(30)	Al Mylar	(30)
Joints, Splices, Fasteners and Tolerance	107 lb/Blkd.	(214)	107 lb/Blkd.	(321)
Cylindrical Shell		483		966
Pressure Skin	.03 Al		.03 Al	
		(177)	2 Required	354
Stiffeners (Al)	.82 x .054 @ 4 c/c	(66)	.82 x .054 @ 4 c/c	132
Rings (Al)				
Meteoroid Skin and Attachment Prov.	.02 Al	(158)	.02 Al	316
Insulation and Attachment Prov.	Al Mylar	(35)	Al Mylar	70
Joints, Splices, Fasteners and Tolerance		(47)		94
Hatches and Rings - Lateral and Inter. Compt.	3 @ 93.3	280	5 @ 93.3	467
Hatches and Rings - Docking	1 Required	142	2 @ 142	284
Secondary Structure		210		340
LEM Adapter Mounting		210		210
TOTAL		2,505		3,957

Table 3-28

COMPARATIVE WEIGHTS FOR ALTERNATE FLOOR DESIGNS

Item	Honeycomb Sandwich 4.0-inch Depth		Honeycomb Sandwich 6.0-inch Depth		Beam Supported Integrally Stiffened	
	Unit Detail	Weight (lb)	Unit Detail	Weight (lb)	Unit Detail	Weight (lb)
Pressure Skin	.05 Al 2 Required	256	.04 Al 2 Required	208	.04 Al 1 Required	104
Support and Stabilizing Structure		338 302		463		343
Honeycomb Core	$4.2\ lb/ft^3$ $6.25\ lb/ft^3$	(230) (26)	$4.2\ lb/ft^3$	(372)		
Foam Attach Rings & Cross Members	$17.0\ lb/ft^3$ @ 3/8" thick	(18)	$17.0\ lb/ft^3$ @ 3/8" thick	(27)		
Adhesive	$.1\ lb/ft^2$/face	¿(35)?	$.1\ lb/ft^2$/face	(35)		
Beams						(234)
Stiffeners						(72)
Radial Skin & Beam Attach Provision		(14)		(14)		(20)
Floor Interconnect Provision	Fiber Glass	(15)	Fiber Glass	(15)	Al Poles	(17)
Tolerances, Fillets, etc.	10%	59	10%	67	15%	70
Insulation Installed	$.084\ lb/ft^2$	15	$.084\ lb/ft^2$	15	$.084\ lb/ft^2$	15
Meteoroid Shield Installed	.02 Al	58	.02 Al	58	.02 Al	58
Total - Less Docking Ring		726 691		811		590

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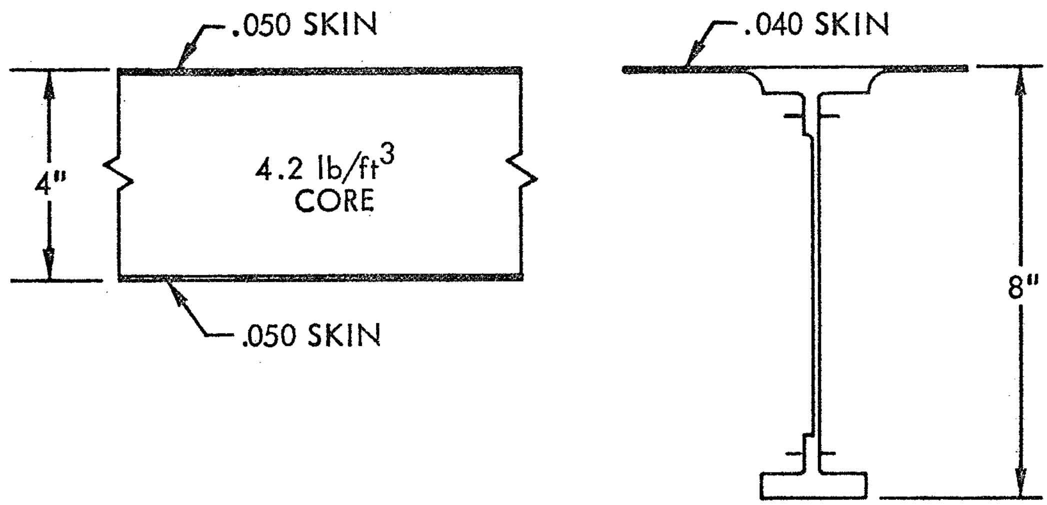
Table 3-29

FLOOR AND CEILING DESIGN



	Honeycomb	Beam
Total Weight 1 Floor	726 lb	590 lb
Walking Surface	.050 Alum.	.040 Alum.
Max. Floor Depth	4.0 in.	8.0 in.
Inspection	Difficult	Conventional
Equipment Mounts	Blind	Accessible
Volume Usability	Unavailable	Usable Between Beams
Outside Attachment	Blind	Accessible

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Table 3-30

COMPARISON OF THE MODULAR APPROACH TO A POINT DESIGN FOR THE INTERIM MODULAR MULTIPURPOSE SPACE STATION

- INITIAL LAUNCH CONFIGURATION
- IDENTICAL MISSION PARAMETERS

Parameter	Modular Approach	Point Design MORL
Crew Size	6 - 9	6 - 9
Subsystem Sizing	9	6
Pressurized Volume (cu ft)	7500	9000
Altitude (n. miles)/Inclination (deg)	200/28.5	200/28.5
Structure, Including Fairings (lb)	12,310	16,000
Subsystems (lb)	16,030*	10,620
Orbit Injection Fuel & Tanks (lb)	1,700	1,700
Discretionary Payload** (lb)	6,760	8,480
EFFECTIVE INITIAL LAUNCH WEIGHT (lb)	36,800	36,800

*Includes 1 kw fuel cell (1610 lb)

**Discretionary Payload includes mission consumables, containers, spares, experimental equipment and startup provisions of 1160 lb.

Table 3-31

SUBSYSTEM WEIGHT COMPARISON FOR MODULAR AND POINT DESIGNS OF INTERIM SPACE STATION

- 1-a 9 Man Subsystem with O_2 Regeneration
- 2-a 10 kw Subsystem
- 3-a 9 Man Subsystem

- 1-b 6 Man Subsystem with O_2 Storable
- 2-b 6 kw Subsystem
- 3-b 6 Man Subsystem

Subsystem		Modular Approach (pounds)		Point Design (pounds)
Environmental Control	(1-a)	2450	(1-b)	1960
Electrical Power	(2-a)	7620	(2-b)	4100
Reaction Control		330		320
Communications		1170		1140
Data Management		230		350
Navigation & Guidance		230		280
Stabilization & Control		690		560
Display Panels & Instrumentation		460		450
Crew Prov., Trim & Furnishings	(3-a)	1650	(3-b)	1350
Subtotal		14,830		10,510
Radiation Shield Prov.		1200		110
TOTAL (lb)		16,030		10,620

Table 3-32

COMPARISON OF THE MODULAR APPROACH TO A POINT DESIGN FOR THE OPERATIONAL MODULAR MULTIPURPOSE SPACE STATION

- INITIAL LAUNCH CONFIGURATION
- IDENTICAL MISSION PARAMETERS

Parameter	Modular Approach	Point Design LORL
Crew Size	24 - 36	24
Subsystem Sizing	36	24
Pressurized Volume (cu ft)	69,530	69,530
Altitude (n. miles)/Inclination (deg)	260/29.5	260/29.5
Structure, Including Fairings (lb)	108,860	106,640
Subsystems (lb)	52,550	46,320
Orbit Injection Subsystem, Fuel and Tanks (lb)	8,700	8,700
Discretionary Payload* (lb)	77,390	85,840
EFFECTIVE INITIAL LAUNCH WEIGHT (lb)	247,500	247,500

*Discretionary Payload includes mission consumables, containers, spares, experimental equipment and startup provisions of 4650 lb.

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Table 3-33

SUBSYSTEM WEIGHT COMPARISON FOR THE MODULAR AND POINT DESIGNS OF THE OPERATIONAL SPACE STATION

Subsystem	Modular Approach (pounds)	Point Design (pounds)
Environmental Control	9,400	8,300
Electrical Power	20,640	18,340
Reaction Control	1,150	1,150
Communications	2,210	2,210
Data Management	580	580
Navigation & Guidance	300	300
Stabilization & Control	5,000	5,000
Display Panels & Instrumentation	1,830	1,830
Crew Prov., Trim & Furnishings	6,600	5,380
Subtotal	47,710	43,090
Radiation Shield Provisions	4,840	3,230
TOTAL (lb)	52,550	46,320

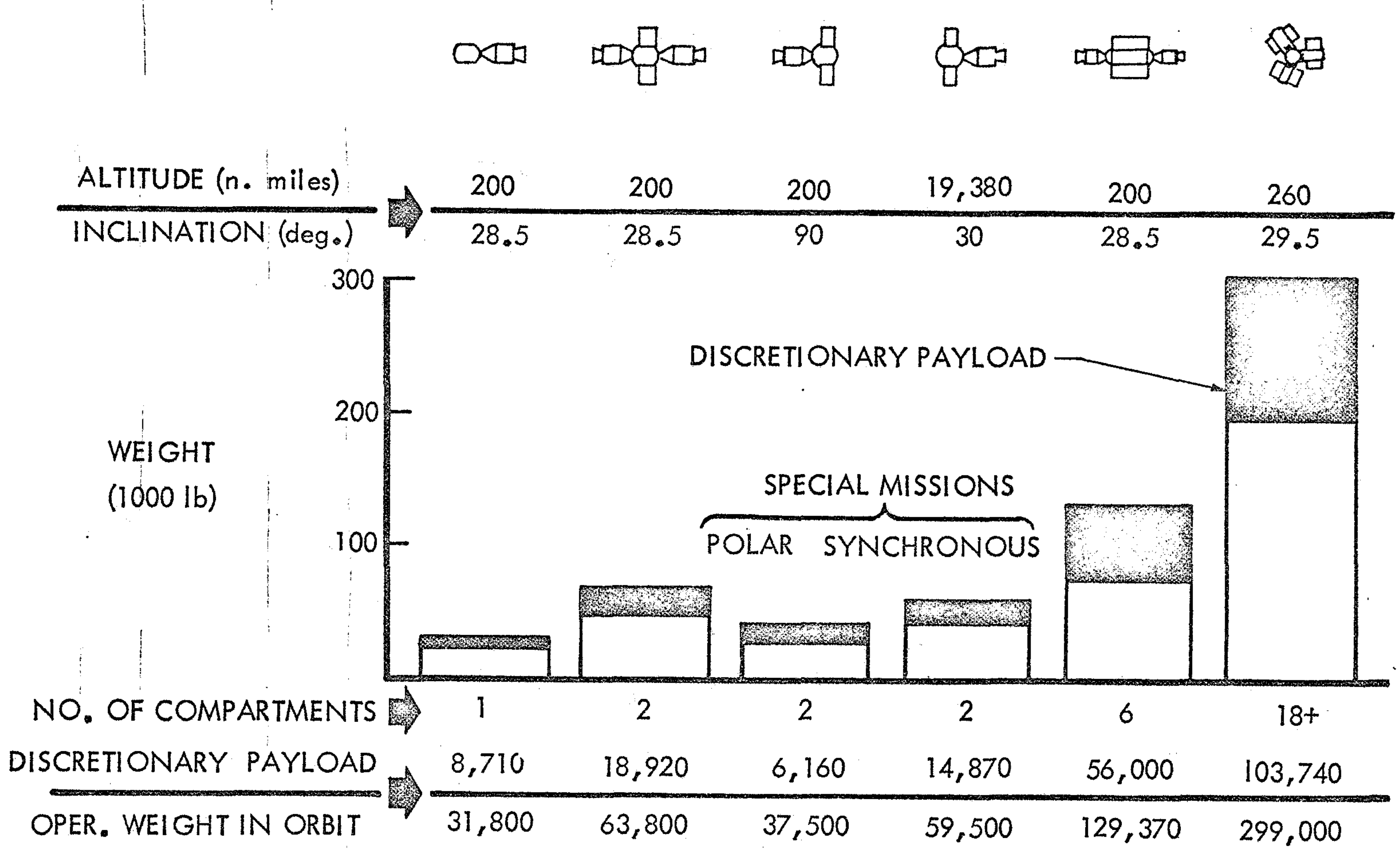

FIG. 3-40 WEIGHT-IN-ORBIT COMPARISON, INITIAL MANNING LAUNCHES INCLUDED

Table 3-34

MODULAR SPACE STATION IN-ORBIT COMPARISON

Item	One-Compartment Dependent Laboratory	Two-Compartment Independent Laboratory	Two-Compartment Polar Laboratory	Two-Compartment Synchronous Laboratory	Interim Modular Multipurpose Space Station	Operational Modular Multipurpose Space Station	Operational Modular Multipurpose Space Station
Altitude (n. miles)	200	200	200	19,380	200	260	260
Inclination (deg)	28.5	28.5	90	30	28.5	29.5	29.5
Compartments	1	2	2	2	6	18+	18+
Crew Size	3	6	3	3	9	24	36
Launches to Man (Initial + Logistic)	1	1+1	1	1	1+3	1+2	1+3
Launch Vehicle (Station and Logistics)	SIB	SIB+SIB	SV/3 stage	SV/3 stage	SIB+SIB	SV+SIB	SV+SIB
Station Pressurized Volume (ft^3)	1250	2500	2500	2500	7500	69,530	69,530
Days of Supplies Carried	45+5	90+90	90+30	90+45	90+90	90+90	90+90
Weight In Orbit (Initial + Logistic)	31,800	63,800	37,500	59,500	129,370	299,000	329,700
Initial	31,800	31,800	37,500	59,500	33,370	237,600	237,600
Logistic	-	32,000	-	-	96,000	61,400	92,100
Discretionary Payload (Initial + Logistic)	8710	18,920	6160	14,870	56,000	103,740	119,240
Initial	8710	2120	6160	14,870	5600	72,740	72,740
Logistic	-	16,800	-	-	50,400	31,000	46,500
General Information							
Weight In Orbit per Crewman	10,600	10,630	12,500	19,870	14,400	12,500	9150
Discret. Payload per Crewman	2900	3160	2050	4960	6220	4320	3320
Supply Required (lb/man)	1800	1800	1540	1470	1670	1540	1400
Experimental Weight	1100	1360	510	3490	4550	2780	1920
Pressurized Volume per Man (ft^3/man)	417	417	833	833	833	2900	1930